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PHOTOGRAPHY
ITS PRINCIPLES AND PRACTICE

A Manual of the
Theory and Practice of Photography

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THIRD EDITION—THIRD PRINTING

NEW YORK CITY
D. VAN NOSTRAND COMPANY, Inc.
250 FOURTH AVENUE

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First Published, January 1927
Second Printing August 1928

Second Edition, November 1930
Reprinted, March 1931, July 1932
February 1935 February 1937

Third Edition, November 1938
Reprinted, February 1939, November 1939

Printed in the U. S. A.

LANCASTER PRESS, INC., LANCASTER, PA.

TO MY PARENTS

and

A VERY DEAR FRIEND

PREFACE TO FIRST EDITION

Manifold as are the applications of photography in all branches of science and industry and great as has been the increase in our knowledge of its basic principles in recent years, comprehensive and adequate instruction in the subject has been largely neglected by our universities and technical institutions. Despite its daily application to the practice of almost every branch of science and industry, and indeed in every walk of life, as well as its importance from the standpoint of pure science, there is not, within the knowledge of the writer, a single university or technical institution in this country which offers a thorough and complete course in the science and practice of photography.

The literature of photography is widely scattered among a large number of journals, some of which have long since disappeared, while until comparatively recently no worthy attempt had been made towards the abstracting and indexing of photographic information. Excluding papers in the periodical press, photographic literature can for the most part be divided into two classes: (1) works of an elementary nature designed for the beginner and paying but scant attention to the fundamental scientific basis of the subject and (2) works of an encyclopedic nature designed principally for reference purposes, such as Dr. J. M. Eder's monumental work in German, the *Ausführliches Handbuch der Photographie* and Fabre's *Traite Encyclopedique de Photographie* in French. Valuable as these works may be, they are not textbooks in the true sense of the word and there is in fact no work dealing both with the science as well as the practice of photography which is especially adapted for use as a test.

The present work is an attempt to meet that need. It embraces the features which several years' experience in the teaching of the subject has shown the writer to be desirable in a work designed for college instruction. No attempt has been made to compile a complete treatise on the subject, while at the same time the fact has been kept in mind that a superficial treatment of the subject, one which is concerned with *effects* rather than causes and with *operations* rather than *scientific principles,* is undesirable in a work of collegiate grade. Accordingly it has been the aim of the writer throughout to present as clearly and as concisely as possible the fundamental principles of the science of photography, omitting nothing of primary importance necessary to an understanding of the subject and paying particular attention to the proper coördination of the facts to one another.

The practical side has not been lost sight of, however, and several of the chapters deal with their subject more from the standpoint of technique rather than science. These, it is hoped, will render the work useful not only to the student but to the practical worker as well.

An apology, perhaps, is due for the omission of certain subjects and for the brief treatment accorded to others. This was, however, to a certain extent, demanded by the scope of the work which is that of a text rather than a treatise. Accordingly a large number of the unsettled controversies have either been omitted, or but briefly treated, as it was felt inadvisable to consider in a work of this nature subjects which still await satisfactory solution.

Footnotes throughout the text will show the extent to which I am indebted to others, while to the following authorities I desire to place on record my appreciation of their invaluable services: Dr. C. E. K. Mees, Dr. S. E. Sheppard, Dr. A. P. H. Trivelli, all of the Eastman Research Laboratory; Mr. F. F. Renwick; Dr. Walter Clark of the British Photographic Research Association; Dr. Hermann Kellner of the Scientific Department, Bausch and Lomb Optical Company; Carl J. Reich of the Gundlach-Manhattan Optical Company; Mr. George E. Brown, Editor of the *British Journal of Photography;* Mr. Frank Roy Fraprie and Mr. E. J. Wall of *American Photography;* Drs. Walters and Davis of the Bureau of Standards; and Miss Bess Spence of this institution who has assisted me in seeing the work through the press. To all others who have assisted in the preparation of this work in any way, a cordial acknowledgment of appreciation is also due.

C. B. NEBLETTE

COLLEGE STATION, TEXAS, 1926

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CHAPTER I

THE HISTORY OF PHOTOGRAPHY

Introduction.—Photography is the science of obtaining images of objects by the action of light on sensitive substances. The word *photography* is due probably to Sir John Herschel and is derived from two Greek words (φῶς = light, αγραφι = write) meaning to draw by light.

The Development of the Camera Obscura.—If all the light is shut out of a room except that entering through a small aperture, an image of objects outside will be formed on a white screen held a foot or so from the opening. No one knows when this simple method of forming an image was first observed. The first clear and unmistakeable reference to it is in the *Problemata* of Aristotle published about 350 B.C. From the time of Aristotle there is no further mention of this method of forming an image for several hundred years. Passages in the *Perspectiva* and *Opus Majus* of Roger Bacon and the *Thesaurus Opticae* of Alhazen are too vague to be considered seriously.

A manuscript of Leonardo da Vinci which must date from sometime prior to 1519 but was not published until 1797 contains a diagram showing the arrangement of the aperture, the screen and the course of the light rays.[1] That Da Vinci does not refer to it as an invention may imply that the principle was already well known. We know for a certainty that the principle of the camera obscura was known in Italy and also in Germany before Leonardo's manuscript was published since Maurolycus of Messina in his *Photismi de Lumine et Umbra ad Perspectivam et radiorum incedentiam facientia,* published in 1611, treats mathematically the formation of images in this way and Erasmus Remhold and his pupil Gemma Frisius early in the 16th century employed this method in observing eclipses without danger to the eyes.

Since scientific works of these times were invariably written in Latin, and the Latin word for an enclosure or room is *camera,* a darkened room with an opening through which light was admitted to form an image became known in time as a *camera obscura.* Jean Baptiste Porta, often credited with the invention of the camera obscura, was only its popularizer. His *Magia Naturalis* (1553), a compilation of the pseudo-science and magic, was immensely popular and served to make known the principle of the camera obscura to a much larger audience than had the scientific works of those who had preceded him.

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[1] Venturi, Essai sur les Ouvrages physico-mathématiques de Leonardo da Vinci, Paris 1797.

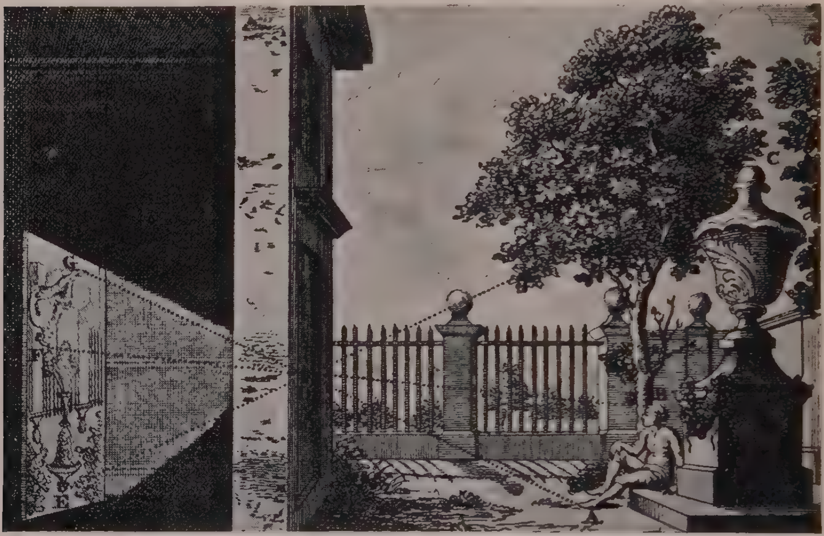


FIG. 1. The Camera Obscura. (From an Old Print)

Camera Obscura With Lens.—Sometime between the thirteenth and the sixteenth century the use of lenses was discovered, or it may be more correct to say rediscovered, for the use of lenses for certain purposes was known at least as early as the time of the Roman Emperor Nero and possibly at a still earlier period by the Chaldeans and Chinese. Roger Bacon seems to have known something of the properties of lenses, but just how much is not clear.

The first definite description of a camera obscura with a lens occurs in a work on perspective *La Practica della Perspectiva* by a Venetian nobleman, Daniello Barbaro, published in 1568. Sixteen years later (1584) another description of a camera obscura with a lens appears in a book of mathematical and physical observations published by Giovanni Battista Benedetti and finally Kepler in his *Dioptrice* published in 1611 deals at length with the principles of the camera obscura and the advantages of a compound lens over the simple plane convex lens described by Barbaro.

The use of a lens in place of a small aperture improved both the definition and the brilliancy of the image. After this time the camera obscura became well known and many different models were developed for various purposes.[2]

Early Photochemistry.—Before proceeding with the development of the camera obscura into the camera, it is more convenient to notice some of the early steps which led to the discovery of a means of retaining, or fixing, the image formed in the camera obscura. One of the many common evidences of the action of light which could hardly escape the notice of man, even in the savage state, is the tanning of the skin. This action is so slow, however, that it is not sufficiently striking to excite more than casual attention.

Since in general photography is concerned with light-sensitive compounds of silver we may pass over those observations of the alchemists of the middle ages on the alteration of other substances upon exposure to light or the atmosphere. The first observations of the sensitivity of silver salts, recorded by Pliny in the first century, are only a record of the action of the atmosphere on metallic silver. In the eighth century Geber observed the darkening of silver nitrate, and Georgius Fabricus, in 1556, the darkening of horn silver, a crude form of silver chloride found in the mines of Frieburg; which both attributed to the action of vapors in the atmosphere. That the darkening of silver salts, and particularly silver chloride, is due to light and not to the action of various vapors of the atmosphere was definitely recorded by Johann Heinrich Schulze in 1727 (Fig. 2). Schulze coated paper with a solution of silver chloride and by exposing it to light made copies of stencils cut in black paper. For this achievement he has been termed the discoverer of photography, but this is unfair to others as he did not attempt to use the camera obscura nor was he successful in finding a means of rendering the image permanent. When exposed to light it rapidly darkened all over.[3]

Carl Wilhelm Scheele, the great Swedish chemist, investigating the chemical changes involved in the darkening of silver chloride, dis-

[2] See Von Rohr & Court, *Phot. Jl.* 75 (1935), 54.

[3] A translation of Schulze's paper appeared in *Phot. Jl.* 38 (1898), 53.

For readers of German there is an interesting biography of Schulze by Eder —Johann Heinrich Schulze, Wein, 1920.

Waterhouse—History of the Camera Obscura. Phot. J., 40 (1900), 270.

covered that the material was decomposed to silver with loss of chlorine. He also noted the difference in the rates of darkening obtained with light of different colors. Scheele, remarks Dr. S. E. Sheppard,[4] should be regarded as the founder of the photochemistry of the silver salts. The closing years of the eighteenth and the nineteenth century witnessed a large number of observations on the action of light on various substances, but as these played no part in the invention of photography they may be passed over.

FIG. 2. Johann Heinrich Schulze. (From Eder, Handbuch)

The Beginnings of Photography—Wedgwood & Davy.—The first definite step towards the discovery of photography was made by Thomas Wedgwood, fourth son of the great English potter, at the turn of the century. Wedgwood, together with Humphrey Davy, then a rising young chemist, repeated the work of Schulze with silver nitrate. They were able to make prints of leaves and similar objects,

[4] *J. Chem. Ed.* 4 (1927), p. 300.

WATERHOUSE—The Development of Photography with Salts of Silver. Phot. J., 43 (1903), 159.

but were unable to prepare a paper sufficiently rapid to permit its use in the camera obscura. Davy made some important additions to the work of Schulze. He found that silver chloride was more sensitive than silver nitrate, and that by using the concentrated light of a solar microscope, he was able to secure images of small stationary objects. But neither Wedgwood nor Davy were able to find a means of "fixing" the image or dissolving the unacted-upon silver salt so as to render the image permanent. The poor health of Wedgwood was no doubt partly responsible for this, and the whole subject was abruptly terminated by his death at the early age of thirty-one years. After his death, a joint paper, written probably by Davy, was brought before the Royal Institution and appeared in the Journal for 1802 under the following title: *An Account of a Method of Copying Paintings upon Glass, and of Making Profiles by the Agency of Light on Nitrate of Silver,* by T. Wedgwood with observations by H. Davy.

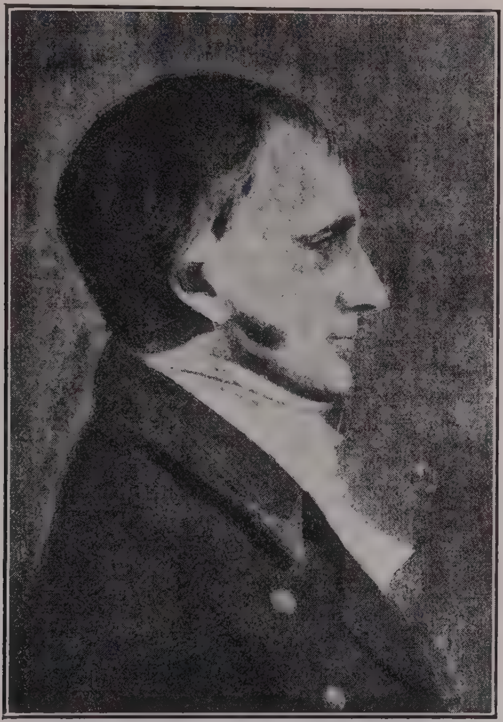
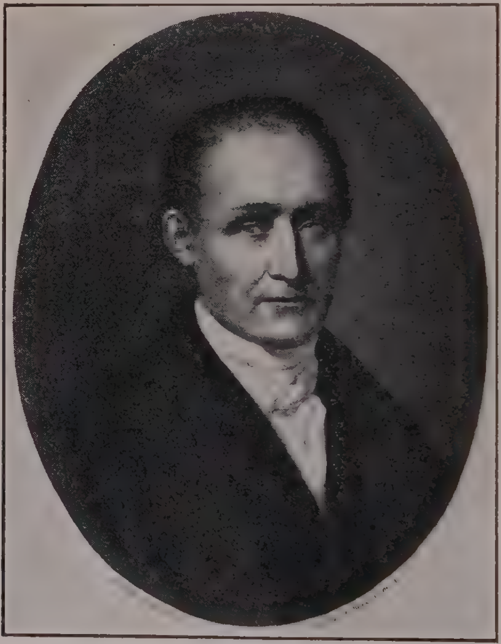


FIG. 3. Thomas Wedgwood. (Chalk drawing, author unknown)

Niepce.—The first to produce a permanent image was Joseph Nicephore Niepce, who was born at Chalons, France, in 1765 and died in 1833. Unfortunately Niepce left no written account of his work and our only source of information is his correspondence with his brother Claude who lived in London during most of the time Nicephore was occupied with these investigations. We know that he became very much interested in the process of lithography, and in 1813 experimented with silver chloride in an effort to copy designs on the stone so as to save lithographers the labor of transferring the drawing by hand. In 1826 he discovered that bitumen, or "Jews' pitch," which is originally soluble in oil of lavender or other essential oils, is rendered insoluble upon exposure to light.



(Courtesy of the Société Française de Photographie)

FIG. 4. Joseph Nicephore Niepce

Metal plates coated with a layer of bitumen were exposed beneath the transparent tracing to be reproduced, then bathed in oil of lavender which removed the bitumen from the unexposed portions of the plate leaving bare the metal base. These portions were then etched in an acid bath, the bitumen remaining in the exposed portions acting as a resist; thus producing an image in relief from which Niepce was able to make a paper print in an ordinary printing press by applying ink to the raised portion. A print produced in this manner by Niepce in 1826 is shown in Fig. 5.

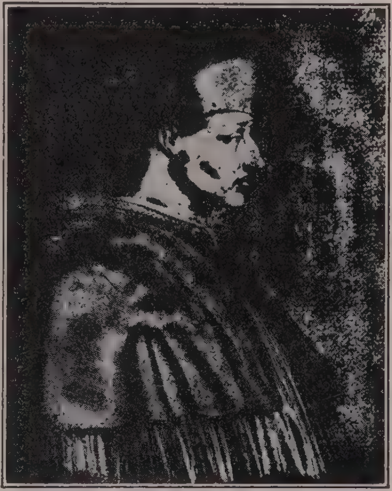


Fig. 5. A Heliographic Print by Niepce, 1826

Niepce was successful this same year in the use of the camera obscura[5] but the exposure required by this process was enormous—from 6 to 10 hours in bright sunlight—and the results were flat and lacking in contrast and detail, so that while Niepce was the first to make a permanent photograph, his process was of little practical value.

Daguerre.—The first to develop a practical process was Louis Jacques Mande Daguerre, born at Cormeilles, near Paris, in 1787, and died Petit-sur-Marne 1851. As a scene painter, Daguerre had used the camera obscura in a series of panoramic paintings of the cities of Europe; and it was undoubtedly this which induced him to undertake the fixing of the image by the action of light on a light-sensitive substance. His investigations began apparently about 1824. Two years later he received word, probably from Chevalier, an optician from whom he had purchased some of the apparatus necessary for his experiments, that the subject was occupying the attention of a man in the Provinces, one Joseph Nicephore Niepce. Daguerre immediately wrote to Niepce suggesting an exchange of secrets, but Niepce was distrustful of Daguerre, who by now was a popular figure in Paris, owing to his invention of the Diorama. Not until 1827, when he met Daguerre while on a trip to his brother Claude in England, were cordial relations established between the two investigators. In 1829 the two signed an agreement of partnership to continue for ten years, during which each would work to their mutual advantage.

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[5] Cromer, *Bull. Soc. franç. Phot.*, 1922, 9, 69.

After the death of Niepce in 1833, if not before, Daguerre discarded the methods of the older investigator and returned to the silver salts. In 1835 he advised Isidore Niepce, who had succeeded to his father's interest in the partnership, that he had reached a certain amount of success. After two years more spent in perfecting details, a company was formed to buy out the process for the sum of 200,000 francs. This company, however, was a failure and the two then appealed to the Government. On the recommendation of the Home Minister, the House of Deputies approved a bill bestowing upon Daguerre a life pension of 6,000 francs yearly and one of 4,000 francs upon Isidore

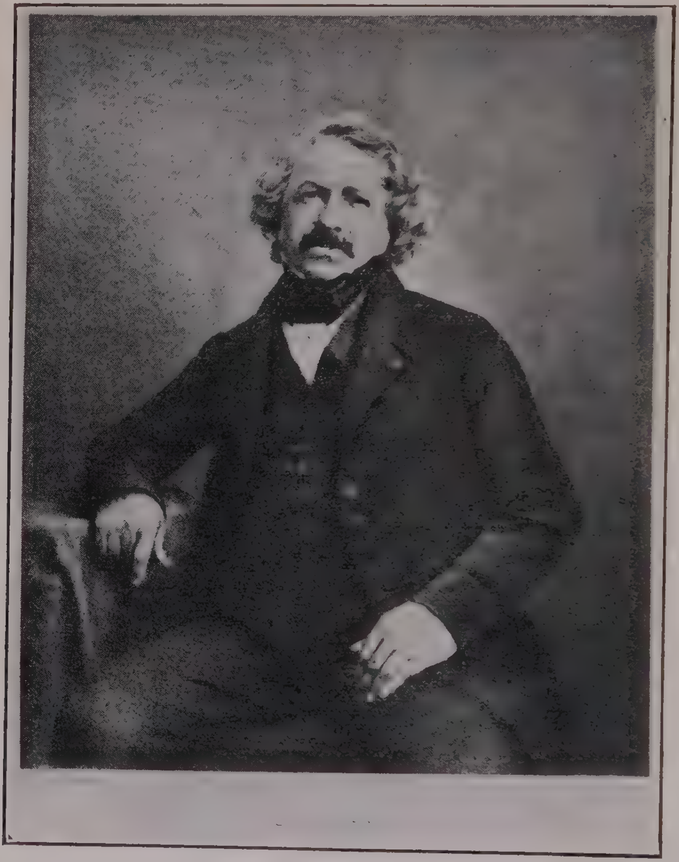

Fig. 6. Louis Jacques Mande Daguerre

Niepce on the condition that the invention be published without patent, this life pension to the inventors being paid by France " for the glory of endowing the world of science and art with one of the most surprising discoveries that honor their native land."

On August 10, 1839, the details of the process were made public by Daguerre himself at a meeting of the Academy of Sciences. A silver plate, or a copper plate covered with silver, was polished and then exposed to the vapors of iodine to produce a light sensitive layer of silver iodide. After an exposure within the camera, which at the time amounted to as much as 10–20 minutes, but was later reduced to a few seconds, the invisible image was brought out or " developed " by exposing the surface of the plate to mercury which is heated. The mercury, by attaching itself to the unexposed portions of silver iodide, produces a positive image. To render the image permanent the unexposed silver iodide remaining was removed by placing the plate in a solution of common salt (sodium chloride). Salt was soon replaced as a fixing agent by sodium thiosulfate, the properties of which had been published by Herschel in 1819, twenty years earlier.

Daguerre's early plates required an exposure of 10–20 minutes but the following year Goddard, of London, discovered the superior sensitivity of silver bromide and one year later the exposure was reduced to a few seconds by the introduction by Voightlander of a rapid portrait lens from the calculations of Josef Petzval of Vienna.

William Henry Fox-Talbot.—Meanwhile, in England, William Henry Fox-Talbot (1800–1877) was assiduously engaged in an attempt to fix the image of the camera obscura. Talbot relates in his *Pencil of Nature,* published in 1844, that in 1833 he was sketching with a camera obscura on the shores of Lake Como but without much success, owing to his inability to draw well. Returning to England in January of the following year, he determined to follow up the work of Wedgwood and Davy. His first experiments were unsuccessful as the paper was not sufficiently sensitive to light. Later (1835) he found that the sensitiveness of the paper was greatly increased by giving it successive washings, first with a solution of common salt, then a solution of silver nitrate and finally exposing it while still wet. In addition he found that a strong solution of common salt would dissolve the unexposed silver chloride and render the image permanent. With paper so prepared he made a photograph of his

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TENNANT-WOODS—Early Daguerreotypers in the United States. Brit. J. Phot., **67** (1920), 420.

home, Lacock Abbey, the same year (1835). Talbot did not publish the results of his work immediately, desiring to perfect the process, but upon news from Paris of Daguerre's discovery he sent a brief communication of the process, which he termed *Photogenic Drawing* to the Royal Institution, and a week later (January 31, 1839) Talbot himself read a paper on his process before the Royal Society. This, it will be noted, was almost eight months before the details of the Daguerreotype process were made public.

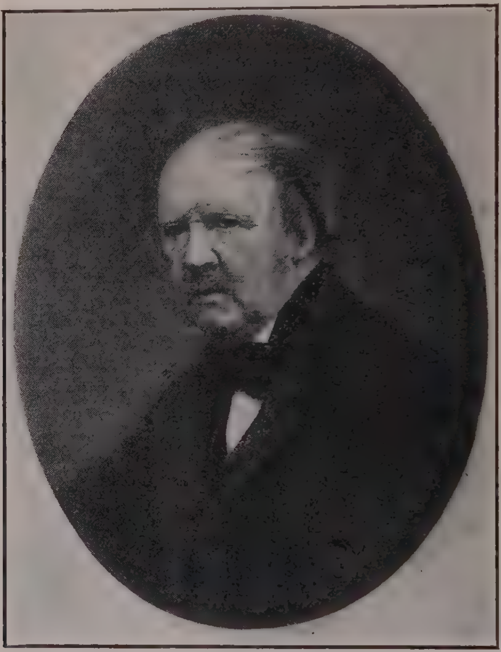

Fig. 7. William Henry Fox-Talbot

In 1840 Talbot patented his *Calotype* (beautiful picture) process. In this process thin, transparent paper was first soaked in a solution containing silver iodide, and then immediately before exposure it was washed over with a solution of gallic acid and silver nitrate. After an exposure of about one minute the paper was developed in gallic acid. Talbot had at last grasped the idea of a developer for bringing out a latent invisible image and thus reducing the exposure. After fixing and drying, prints were made by exposing another sheet of paper underneath the negative, developing in gallic acid, and fixing in hypo (sodium thiosulfate).[6]

Negative Processes on Glass.—Paper is not a satisfactory medium for negatives and attempts were made by Herschel as early as 1840 to use glass. These attempts, however, were unsuccessful as he did not appreciate the fact that images of sufficient density can be obtained only in the presence of albumen, collodion, gelatin or a similar substance capable of holding the light sensitive substance in place on the glass. The need for such a substance was recognized by Niepce de Saint Victor, a nephew of Nicephore, who in 1847 described a process employing albumen secured from the white of an egg. Frederick Scott Archer, of London (Fig. 8), worked out in 1848 and

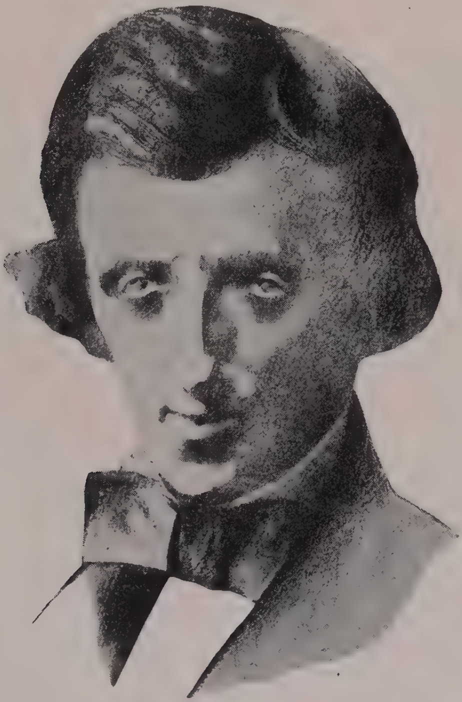

FIG. 8. Scott-Archer (Drawing from old print)

published in 1851 a process employing collodion which was so successful that it speedily supplanted all other processes and remained in general use for over thirty years.

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[6] It is practically certain that in the use of gallic acid as a developer, Talbot was anticipated by an English clergyman, J. B. Reade. Reade's work, however, was unknown at the time.

Collodion, a viscid medium formed by dissolving gun-cotton in alcohol and ether, was discovered by Maynard, of Boston, in 1847. Archer's process is termed wet-collodion because the glass must be coated, the exposure made and developed before the collodion has dried. A clean glass plate was first coated with collodion to which a soluble iodide, such as potassium iodide, had been added. The plate was then sensitized by immersion in a bath of silver nitrate, exposed in the camera while still wet and developed at once, using a solution of pyrogallol and silver nitrate, and finally fixed in sodium thiosulfate, or hypo. At no stage in the process may the collodion become dry or the picture will be lost; hence, when making pictures out-of-doors it was necessary to take along a dark tent in which to prepare the plate and, after the exposure, to develop it. Some idea of the labor and inconvenience involved in making a photograph in those days can be obtained from Fig. 9a which shows the pack carried by the photographer and Fig. 9b, the photographer at work in the field.

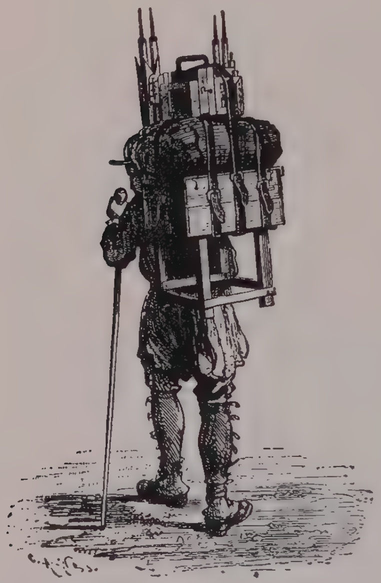

FIG. 9a. The Wet Collodion Process in the Field—Photographer with Pack

In the years which followed, attempts were made to prepare plates which would keep and thus avoid the necessity for a darkroom when making pictures away from the studio. Most of these processes involved the addition of hygroscopic substances to prevent the collodion from drying. The most successful of such processes were those of Taupenot (1855) in France and Norris (1856), of Birmingham. In the first, the plate, after having been coated with collodion in the usual manner, was coated a second time with albumen and then allowed to dry. It was then immersed in a bath of silver nitrate, washed and dried. The process patented by Norris was similar except that gelatin was employed in place of albumen.

In 1864 Sayce and Bolton discovered a practical means of preparing a collodion emulsion. To prepare a so-called emulsion (photographic emulsions are in reality suspensions) silver nitrate was added to iodized collodion; this produced silver iodide by precipitation rather than by immersing the collodion-coated plate in a solution of silver nitrate. After coating, the plates were immersed in a solution of tannin which acted as a preservative and retained the permeability of the collodion. All of these processes were considerably slower than wet-collodion and did not find much acceptance except among landscape photographers.

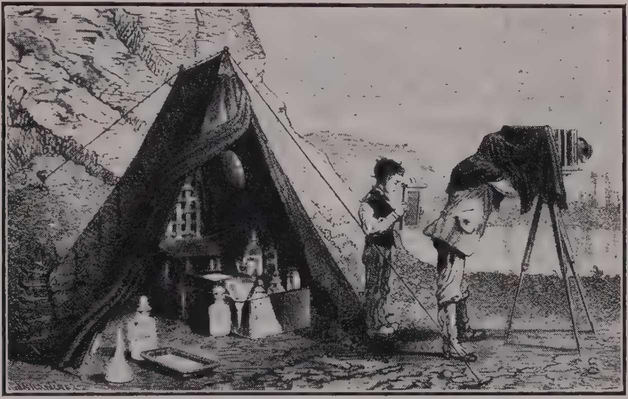

Fig. 9b. The Wet Collodion Process in the Field—Laboratory in the Field

Gelatin Emulsion.—The first recorded application of gelatin to photography is the unsuccessful attempt of Niepce de Saint Victor to use gelatin as a vehicle for holding silver iodide to glass plates. Gelatin, however, became soft and frequently left the glass when the plate was placed in the nitro-acetic silver bath used for sensitizing and was discarded, as we have seen, for albumen. Attempts were made by Gaudin (1853) to prepare what might be termed gelatino-iodide emulsion but his process was not practical. His work, however, led him to recognize the fact that silver bromide is more sensitive than silver iodide in the presence of gelatin. In 1868 Harrison described a method of emulsifying silver bromide in gelatin but the results were unsatisfactory.

Two years later a notable advance was made by an English physician and amateur photographer, R. L. Maddox, who was the first to prepare a gelatino-bromide emulsion capable of producing satisfactory results. In the method described by Maddox, silver bromide was formed in gelatin by precipitation in the presence of an excess of silver. The emulsion thus prepared was coated on glass plates without further treatment and dried. After exposure, the latent photographic image was developed with pyro, intensified with pyro and silver nitrate, and fixed in hypo. Maddox does not appear to have realized the need for washing the emulsion to remove the excess silver salts, although this was the general practice with collodion emulsion processes which were well known by this time. Consequently his emulsion was very slow and suitable only for contact printing. Thus, while it marks an epoch in the development of photography, the process of Maddox was far from perfect.

Very little attention was paid to the work of Maddox at the time but two years later gelatino-bromide emulsion was advertised in the *British Journal of Photography* by Burgess. The method used in its preparation was never published and the venture was unsuccessful financially; he did succeed, however, in proving that excellent results could be obtained with gelatin emulsion and with an exposure no greater than that required with the wet-collodion process then in general use.

A noteworthy advance was made the same year (1873) when King and Johnson independently recognized the importance of removing the superfluous salts in the emulsion and described means for their removal. King's method consisted in placing the emulsion in a bladder, which was then immersed in water to wash out the soluble salts. Johnson's method consisted in chilling the emulsion, then cutting it up into fine shreds and washing the shreds in running water for several hours. Johnson also drew attention to the advantages in emulsification of an excess of soluble bromide.

These advances made possible for the first time the preparation of a really satisfactory emulsion of silver bromide in gelatin. The wet-collodion process began to disappear and from 1873 on the history of negative processes is the history of gelatino-bromide emulsion.

The following year, gelatino-bromide dry plates were placed on the market in England by the Liverpool Dry Plate Company. The term dry plate was adopted to distinguish the process from wet-collodion. Four years later (1878) Bennett, of London, showed that the sensitiveness of a gelatino-bromide emulsion is considerably increased if kept for several days at a temperature of 90 to 95° F. The following year Mansfield showed that this long and troublesome process might be avoided by precipitating the silver bromide in a part of the gelatin, boiling this for a few minutes, and then adding the remainder of the gelatin when the solution had cooled. This procedure so greatly increased the sensitivity of gelatin emulsion that an *instantaneous* dry plate was advertised by Wratten & Wainwright in the *British Journal Photographic Almanac of 1879.*

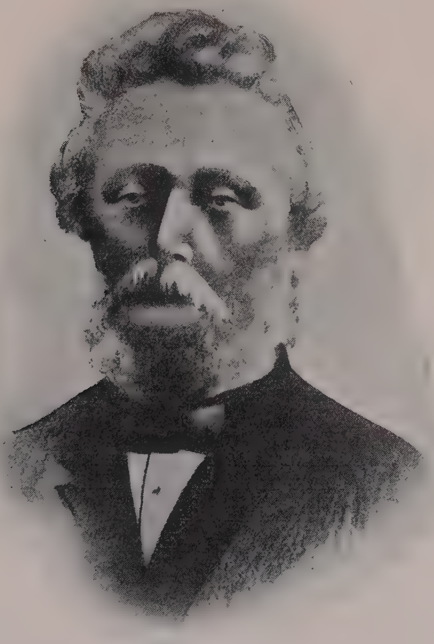

FIG. 10. Richard Leach Maddox

This same year Monkhoven, of Belgium, suggested that the increased sensitiveness produced by heating the emulsion is due to a change in the molecular state of the silver bromide and stated that the same result might be secured by the addition of ammonia. Eder, of Vienna, perfected a process based upon ammoniacal silver the following year. Abney, in England, called attention to the advantages of employing a small amount of silver iodide in gelatino-bromide emulsion.

By this time manufacturers of dry plates were established in England, in Belgium and in the United States; and within the next few years collodion was completely displaced except for some specialized fields, such as photo-engraving, where it is in use today.

Emulsion Supports for Negative Purposes.—Paper was used as a support for the emulsion until 1851 when the wet-collodion process of Scott-Archer using glass plates was introduced. Efforts to replace glass began in 1877 when Palmer was successful in preparing flexible films of gelatin on which the emulsion might be coated. These, however, were not successful commercially. Gelatino-bromide emulsion on layers of hardened gelatin or collodion was placed on the market between the years 1879 and 1881 by Stebbing, Ferrier and Pumphrey. In 1884 Eastman in America patented stripping film. This stripping film consisted of paper coated with a thin layer of soluble gelatin which in turn was coated with a gelatino-bromide emulsion. After developing and fixing, the image was stripped from the paper support and dried on glass. This film was supplied in rolls and a roll holder was provided to adapt it to the plate cameras then in common use. From the standpoint of the general public this was a great advance, but the process was still intricate and difficult for the amateur because of the

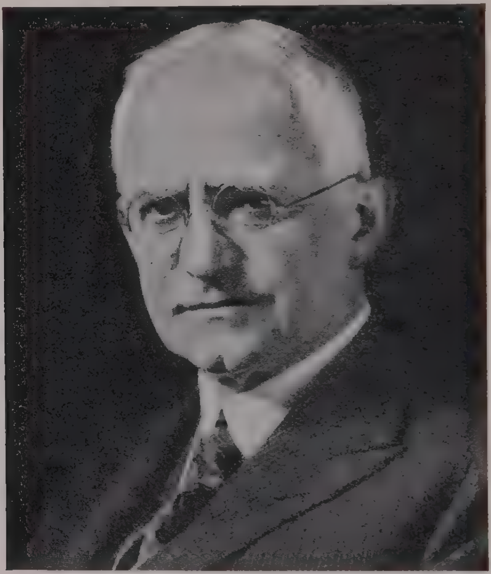

FIG. 11. George Eastman

delicate handling demanded in transferring the image from the paper to the final glass support. Four years later (1889) the stripping film with its paper base gave way to a transparent base of nitrocellulose introduced by the Eastman Dry Plate and Film Company of Rochester, New York, U. S. A. The introduction of a daylight loading camera two years later (1891) brought photography within the reach of all.

History of Color Sensitizing and Color Sensitive Materials.—The sensitivity of the silver halides lies almost exclusively in those portions of the spectrum which produce the visual sensation of blue and violet and in the invisible ultra-violet. In 1873, Vogel of Berlin observed that a certain collodion emulsion which had been dyed with a yellow dye to prevent halation had a different sensitivity from those which had not been dyed. This effect was traced to the dye and thus was discovered the principle of dye sensitizing. Continuing his investigation, Vogel found a number of dyes which act as sensitizers, the most important being cyanine and quinoline red (1884) neither of which is in use today. In 1874 Waterhouse of London found that eosin was a yellow-green sensitizer for collodion emulsion and Clayton and Tallifer patented in England and France its use with gelatin emulsion. Eder of Vienna found that erythrosin, the iodine analogue of eosin, was still better and for a number of years it was the best known sensitizing dye for the green region. Shortly thereafter dry plates sensitized with erythrosin were placed on the market by most manufacturers as *orthochromatic* or *isochromatic plates.*

In 1902, Miethe and Traub discovered the sensitizing properties of Ethyl red, an analogue of cyanine, and the following year Köenig of the Hoechst dye works introduced in rapid succession a number of yellow and green sensitizers the more important being Orthochrome, Pinaverdol, and Pinachrome. A satisfactory red sensitizer was not discovered until 1906 when Homolka, of the Hoechst dye works, discovered a carbocyanine dye which was introduced as Pinacyanol. Panchromatic plates sentitized with pinachrome and pinacyanol were placed on the market in 1906 by the firm of Wratten and Wainright in England.

In recent years the work of Mills, Hamer, Pope, Brooker and others has made available a number of new sensitizers much more efficient than those previously known. These new sensitizers are derived

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Theisen—The History of Nitrocellulose as a Film Base. J. Soc. Mot. Pict. Eng., **20** (1933), 259–266.

from thiazol bases rather than quinoline and have the advantage over the older sensitizers of not lowering the general sensitivity of the emulsions nor increasing fog. In fact with some, fog is less than with the same emulsion not color sensitized. This is particularly the case with slow, fine-grain emulsions. The introduction of panchromatic materials of the hyper-sensitive and super-sensitive types in 1928–1930 marks a new epoch in the history of photographic negative materials.

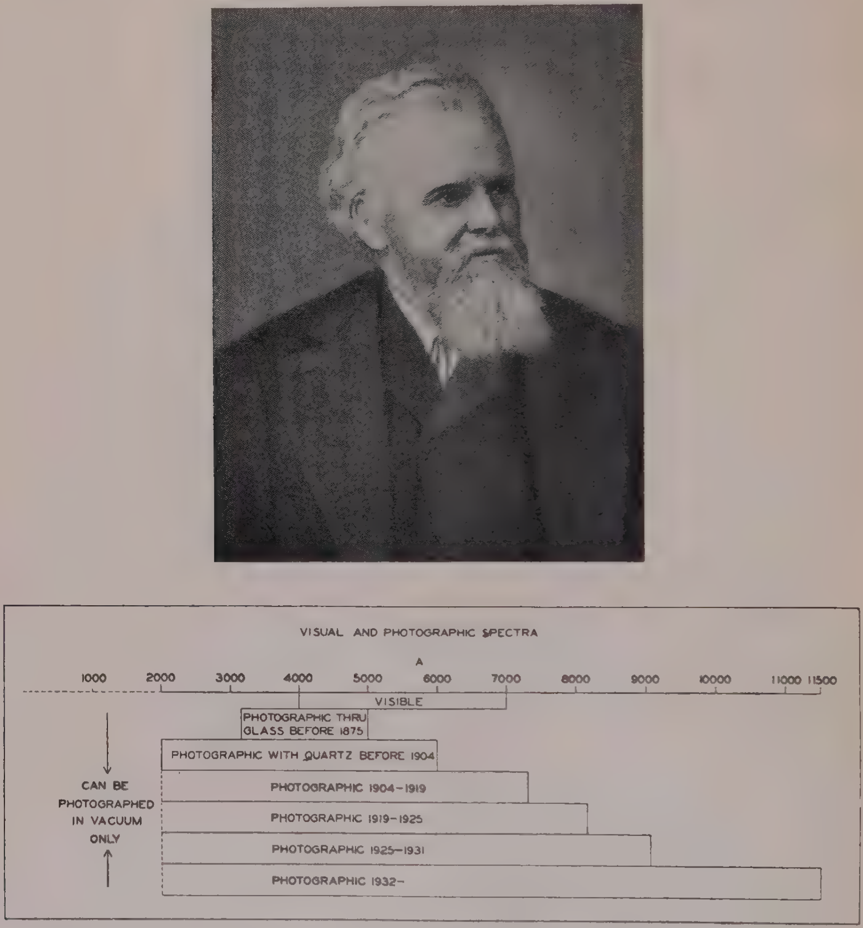

Fig. 12. H. W. Vogel Discoverer of Color Sensitizing (1873) and Chart Showing the Progress Since That Time.

Shortly after the introduction of Pinacyanol, the Hoechst dye works discovered the first sensitizer for the infrá-red, *Dicyanine.* This, while a good sensitizer for the infra-red, is unstable and tends to fog badly so that in practice it cannot be relied upon to yield satisfactory results.

In 1919, Adams and Haller of the U. S. Bureau of Chemistry prepared a new dye similar chemically to pinacyanol but sensitizing specifically in the infra-red with a maximum action at 750 mμ. This was termed *kryptocyanine.* It was many more times powerful as a sensitizer for the near infra-red than Dicyanine and quite free from fogging tendencies. In 1925, H. T. Clarke of the Kodak Research Laboratories separated a new dye from kryptocyanine with a maximum at 850 mμ. This was termed *Neocyanine.*

The sensitizing properties of the tricarbocyanine dyes were discovered in 1930. The sensitizing action of these extends much further into the infra-red; Xenocyanine, described by Brooker, Hamer and Mees,[7] sensitizes to 1100 mμ with a maximum at 980 mμ. Still more recently (1935) an investigation of the tetra- and penta-carbrocyanine by Brooker, Keyes, Köenig and others has resulted in the discovery of several dyes whose sensitizing action extends still further into the infra-red. These have made possible the photography of spectral lines beyond 1300 mμ. The discovery of efficient sensitizers for the infra-red such as Kryptocyanine, Neocyanine and Xenocyanine has made possible infra-red sensitive plates and films suitable not only for spectrography but for general photography, the motion picture industry and aerial photography.

The following chart illustrates diagrammatically the progress which has been made in the sensitizing of photographic materials since 1873 although, of course, it does not indicate differences in the sensitizing powers within a certain spectral range, nor differences in dyes with respect to effect on general sensitivity or fogging tendencies.[8]

History of Developing Substances.—The existence of a latent image and the possibility of converting such an image into a visible one through chemical treatment appears to have been discovered by Daguerre, who quite by accident found that mercury was attracted by the exposed silver halide thus converting an invisible image into a visible one.

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[7] *J. Opt. Soc. (Amer.)* **23** (1933), 216.

[8] This diagram represents a modification of one used by Mees. *Nature* 137 (1936), 729.

Talbot introduced the use of a solution of gallic acid as a developer for silver chloride with his Calotype process (1842) although its properties had been discovered some years previously by an English clergyman and microscopist, the Rev. J. B. Reade.

The oldest of the developing agents now in general use is pyrogallol, which was introduced by Scott-Archer with his wet collodion process in 1852. Pyrogallol was not used in an alkaline solution, however, until 1862, nor was sodium sulfite used as a preservative until 1882.

Ferrous sulfate was introduced by Hunt in 1844 and remained in general use until the wet-collodion process was superseded by gelatino-bromide emulsion. Even then it continued to be used by many of the older workers for some years.

The developing properties of hydroquinone were discovered by Abney, of London, in 1880 and those of pyrocatechin, which is closely related chemically, by Eder and Toch, of Vienna, the same year.

The years between 1888 and 1900 witnessed great activity in the field of developing agents; the developing properties of paraphenylene diamine were discovered in 1888 by Andresen. A year later Andresen introduced *Eikonigen* (sodium-amido-β-naphthol-β-sulfonic acid) whose properties as a developer had been discovered by Meldola. Two years later (1891) the firm of Hauff introduced *Metol* (monomethyl paraminophenol sulfate). This was followed by diaminophenol or *Amidol* (1892); *Ortol* (a combination of hydroquinone and methyl-ortho-aminophenol) in 1896 and *Adurol* (monochloro-hydroquinone or chloroquinol) in 1898. Eikonigen has been superseded by metol, and Ortol is but little used today, but the other three remain in general use with metol the most popular. *Edinol,* the sulfate of oxymethyl paraminophenol, was introduced by Bayer in 1901.

The Brothers Lumiere are responsible for a number of developing agents; *Metoquinone,* a chemical mixture of metol and hydroquinone (1903); *Chloranol,* a combination of hydroquinone and methyl-paraminophenol (1913); and *Hydramine,* a chemical combination of hydroquinone and paraphenylene (1899).

Among organic developing agents no longer available but once popular may be mentioned *Duratol,* a benzyl-paramenophenol, introduced by Schering in 1910; *Diogen,* introduced by Agfa (1893) and said to be sodium-alpha-amido-naphthol-disulfuric acid; *Monomet* (para-amido-ortho-cresol-hydrochloride), introduced in England by the White Band Company 1916; and *Neol,* introduced by Hauff in 1918 and stated to be para-aminosalicylic acid.

Alkaline development appears to have been discovered by Major Russell and Leahy independently (1862). Ammonia was first used but was later replaced by the caustic alkalis and the alkaline carbonates such as sodium carbonate. The use of sodium tribasic phosphate was suggested by Lumiere in 1906 and is finding some favor today in fine grain developer formulas. Acetone and formaldehyde were introduced by Lumière in 1896 and 1898. The former is now seldom used but formaldehyde is used in a number of developers for use with films designed for photo-mechanical purposes. Borax and certain related compounds have come into general use in recent years in fine grain developers. The first developing formulae of this type to become popular were those of Wellington and Capstaff.[9]

The use of sodium sulfite as a preservative in solutions of organic developers appears to be due to Berkley (1882). Acid sulfites such as potassium meta-bisulfite and sodium bisulfite were recommended by Mawson and Swan (1887).

Development of Printing Processes with Silver Salts.—For printing from negatives made by his Calotype process Talbot employed what we term today the salted paper process. Paper of suitable surface is immersed in a weak solution of salt, after which it is dried. Just before use it is sensitized by immersion in a solution of silver nitrate and dried, exposed to light beneath the negative until sufficiently dark and fixed in hypo. Le Gray introduced the toning of the print with gold chloride as a means of improving the color in 1849.

The incorporation of albumen with the salting solution to give the paper a gloss finish and keep the silver salts on the surface appears to have been suggested by Le Gray although often credited to Fox-Talbot. For more than 30 years albumen paper was practically the only process of printing in general use. Paper coated with albumen was supplied ready for sensitizing in a solution of silver nitrate by the photographer. In 1870 Adolph Ost of Vienna discovered that the addition of a citrate enabled the sensitized paper to be kept for several months which made it possible to supply the photographer with ready-sensitized paper.

A method of using collodion in place of albumen was described by G. Wharton Simpson in 1864 and collodio-chloride of silver papers were introduced commercially by Obernetter, of Munich, two years later, but the process did not attract much attention until the introduction of a much improved product by Liesegang, of Düsseldorf, in 1886.

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[9] Capstaff & Seymour: *Amer. Phot.* **21** (1927), 98.

Gelatino-chloride papers appear to have been first employed by Palmer and Smith as early as 1866, but no details were published. Full details for the preparation and use of gelatino-chloride papers were published by Abney in 1882 and were introduced commercially two years later by Obernetter, of Munich, and a few years later by Liesegang, of Düsseldorf, and Ilford of London.

The above papers are all members of the class known as printing-out papers; that is, they produce a visible image upon exposure and there is no after development. The now popular developing papers appear to have had their prototype in a process used by Blanquart-Evard in 1851, but it was not until 1874, after paper coated with gelatino-bromide emulsion had been introduced by the Liverpool Dry Plate Company, that developing papers made any headway. In 1880 Morgan and Kidd established a factory at Richmond (England) and in 1885 Eastman, of Rochester, introduced the machine coating of paper in the roll with gelatino-bromide emulsion, after which gelatino-bromide paper began to assume importance as a printing process.

Directions for the preparation and use of emulsions of silver chloride for positive printing were published by Eder and Pizzighelli in 1881. The first papers of this type were introduced commercially by Dr. E. Just, of Vienna, in 1883 and shortly afterward in England by Edwards and Warneke, but "Velox," introduced in America by the Nepera Chemical Company from the formula of Dr. Leo Baekeland, was the first to achieve wide popularity. Its successful introduction paved the way for a large number of similar papers in all important countries.

The use of gelatino-chloro-bromide emulsions for positive prints was introduced also by Eder and Pizzighelli in 1883. Chloro-bromide emulsions are especially adapted to the production of warm-tone images and papers of this type are widely employed for portrait work at the present time.

Platinum Printing Processes.—The sensitiveness of certain compounds of platinum especially in the presence of an organic salt, such as ferrous oxalate, was observed by Herschel in 1832. Robert Hunt, in 1854, attempted to develop a printing process employing platinum chloride and ferric oxalate but was unsuccessful. The first practical process was patented by William Willis of London in 1873. In this process paper coated with potassium chloroplatinite and ferric oxalate is exposed under the negative until a faint image appears. It is then placed in a solution of potassium oxalate, in which the reduced iron salt is soluble, and as it is dissolved by the oxalate, it attacks the platinum compound reducing it to the metallic state.

A direct printing out process requiring no development was perfected by Hubl and Pizzighelli but has never been widely used.

Printing Processes Employing Compounds of Chromium.—The observation that certain compounds of chromium are sensitive to light appears to be due to Mungo Ponton, an Englishman, who in 1839 discovered that paper soaked in a bichromate and dried was sensitive to light. The following year Becquerel found that gelatin, gum, and similar substances are rendered insoluble when exposed to light in the presence of a bichromate. In 1855 Alphonse Poitevin patented a process of printing in which paper with a layer of gelatin containing a pigment was sensitized in potassium bichromate and exposed to light. Then upon washing in water, the soluble gelatin in the unexposed portion washed away leaving an image formed by the pigment held in the insoluble gelatin. Poitevin's results were unsatisfactory as were those of John Pouncy, of Dorchester, who patented a similar process in 1858.

Laborde the same year pointed out that in the half tones only the upper portion of the gelatin layer is rendered insoluble on exposure, as the lower strata remain soluble, so that the image washes away. To avoid this, Blair, Burnett and Schouwaloff independently and almost at the same time (1858) suggested that the exposure be made through the paper so that the exposed layers would lie next to the base of the paper. Fargier in 1860 coated the exposed film with collodion and then washed away the soluble gelatin from the back. Pigment printing was placed on a practical basis by Swan when he patented carbon tissue in 1864. The carbon tissue, which is simply paper coated with gelatin and a suitable pigment, is sensitized with a bichromate, dried and exposed. The gelatin layer is then transferred to another support thus placing the soluble gelatin on the surface from which it is removed by washing in water.

Gum-bichromate is a non-transfer process of pigment printing based upon the original work of Poitevin and Pouncy. Washing away of the highlights is to a large extent prevented by using a thin layer of pigmented gelatin and building up an image by successive printings. The process was brought to the front about 1895 largely as a result of the pictorial work of Demachy, Puyo and other French pictorialists.

Marion, in 1873, found that paper immersed in a solution of potassium bichromate, dried and exposed to light under a negative so as to form a faint image, will transfer the image to a sheet of carbon tissue left in contact with it for some time. Manly in 1899 patented a similar process which was termed *Ozotype* and in 1905 another known as *Ozobrome*. In the latter a sheet of carbon tissue was soaked in a solution of potassium bichromate, ferricyanide and bromide. The sheet of carbon tissue is placed in contact with a bromide print for several minutes, transferred to another support and developed by washing in water as usual. The bromide print thus takes the place of the negative and there is no exposure to light. Ozobrome was revived in an improved form by H. F. Farmer in 1919 as *Carbro*—carbon from bromides—and has proved quite successful.

The Development of the Oil, Bromoil and Powder Processes.—A second process was worked out and patented by Poitevin in which a bichromated gelatin film *without pigment* was exposed under a negative. This gelatin film upon exposure to light under the negative became more or less insoluble in various portions according to the gradations of the negative. When immersed in water, the soluble gelatin absorbs water and becomes so charged with water that it will repel a greasy ink, while the shadows, being insoluble, do not absorb water and will accept the ink. Accordingly when a roller charged with greasy ink is passed over the print, an image is formed in greasy ink which adheres to the shadows but not to the highlights of the print. This process was the forerunner of a number of photo-mechanical processes, which are beyond the scope of this work, and the oil, bromoil and powder processes.

Two years before (1853) the Duc de Luynes through the Société Française de Photographie had offered a prize of 10,000 francs to the person discovering a process by which absolutely permanent prints might be produced. The President of the Société, M. Regnault, the famous chemist, in announcing the offer called attention to the permanency of carbon and suggested that experiments be conducted with a view to obtaining prints in carbon. Two Frenchmen, Garnier and Salmon, starting from Poitevin's patent of 1855 worked out a process in which the bichromated gelatin was exposed to light under the negative, soaked in water, and then pure finely divided carbon dusted over it. The carbon adheres only to the unexposed parts and in this way an image is secured. This was the beginning of the so-called powder processes.

Rawlings' process of oil printing (1904) is actually little more than a modification of the process covered by Poitevin's patent of 1855. Rawlings advised the use of brushes rather than a roller for applying the ink; thus it was possible to control the various tones of the print by varying the amount of ink deposited. This feature served to attract various workers who wished to have a ready means of altering the tone values of their prints and the process rapidly gained in popularity among pictorialists.

In 1889, Howard Farmer found that when a gelatin film containing finely divided silver, as in a negative or positive, is immersed in a bichromate, the gelatin in contact with the metallic silver is rendered insoluble exactly as though it had been exposed to light in these portions. Upon this property of a bichromated colloid is based the bromoil process. The first suggestion of the rationale of this process is due to E. J. Wall. It was taken up and worked out practically by C. Welborne Piper.

The Development of the Camera.—Nicephore Niepce, writing in 1816, describes what was probably the first photographic camera as being a box about 6 inches square with a sliding tube carrying the lens. One of the earliest cameras known to have been used by Daguerre is shown in Fig. 13. The mirror at the back was to erect the image for focusing. The camera is focused by means of the rack and pinion on the lens. Later Chevalier built for Daguerre a camera in which the body was divided into two sections (Fig. 14), one sliding within the other and clamped by a screw working in a slot on the baseboard. Although known at an earlier date, the bellows was not generally used until in the fifties.

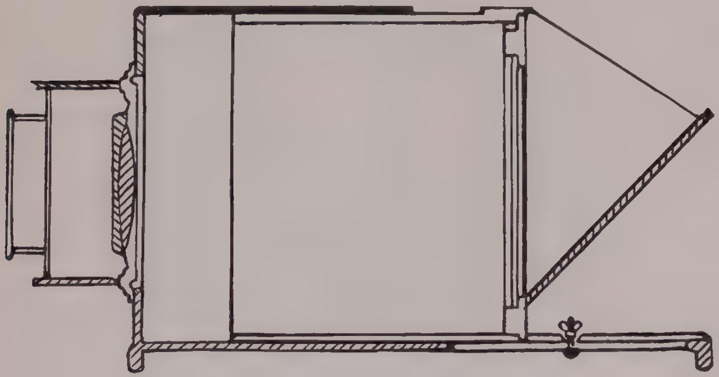

Fig. 13. Cross Section Daguerre's Camera

In the period between 1850 and 1860 the photographic camera began to assume the appearance of the familiar view camera of today although it was much larger, heavier, and clumsier to use. Rising and sliding fronts appear to have been the first of the now familiar adjustments to be added (1847) but by 1860 the swing back had appeared. This was followed after a lapse of nearly twenty years by the reversing back and still later by the swing front which did not appear until 1895 when it was introduced by Sanderson of Cambridge (England). Stand and portrait cameras have not changed fundamentally

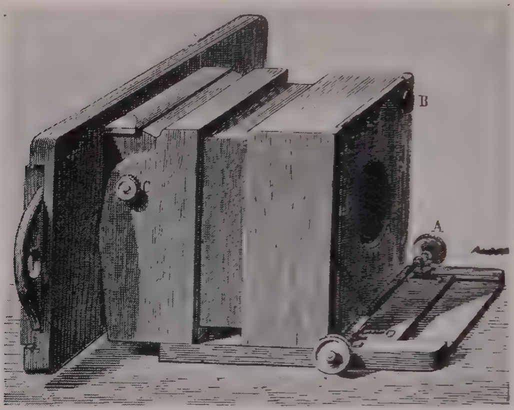

Fig. 14. Early Camera. (Fabre, Traité Encyclopédique de Photographie 1889)

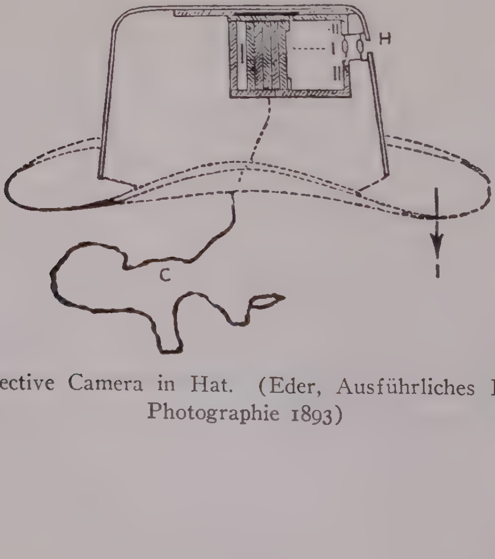

Fig. 15. Detective Camera in Hat. (Eder, Ausführliches Handbuch der Photographie 1893)

in design in the last twenty-five years despite the different types and constructions that have been evolved.

While a small camera for instantaneous exposures in the hand was designed by Skaife in 1858, there was little interest in hand cameras until the late seventies when wet-collodion had begun to give way to gelatino-bromide dry plates. Because the earliest hand cameras were intended principally for making pictures without attracting the attention of the subject, they were usually disguised as books, as opera glasses, or hidden in the hat or under the vest (Fig. 15). Shortly thereafter magazine cameras appeared. These were so designed that a number of plates might be placed in the camera and exposed before reloading. Various devices were employed for changing the plates; one of the best known is shown in Fig. 16.

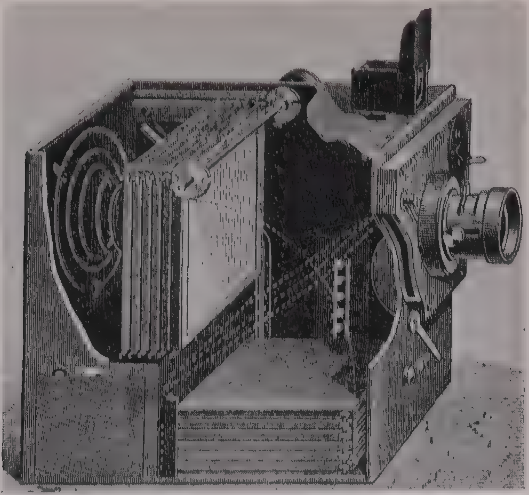

FIG. 16. Magazine Camera from Eder, Ausführliches Handbuch der Photographie

Many of the features of the reflex camera were anticipated in a camera designed by Thomas Sutton of England in 1860. In this camera, the image was reflected to a horizontal focusing screen by a mirror which was swung up out of the way before making the exposure. The primary purpose of the design was to enable the image to be seen "right side up" on the focusing screen and the interconnection of the mirror and the shutter which forms an integral part of

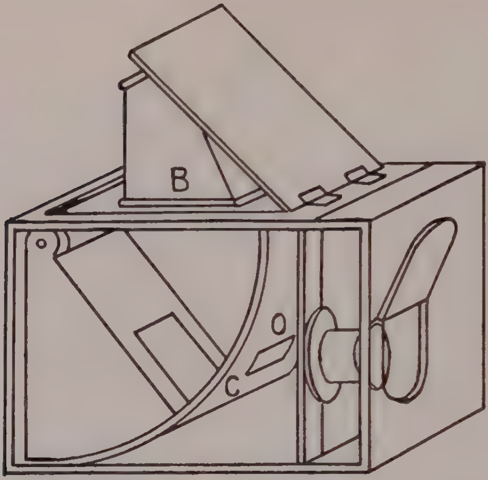

FIG. 17. Manerizzi's Reflex

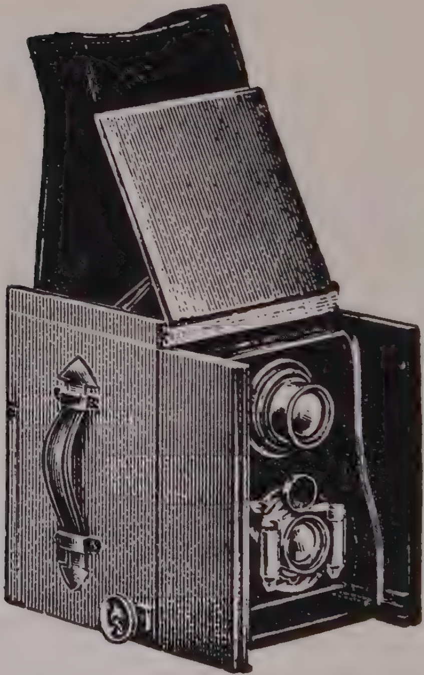

FIG. 18. Older Form of Twin Lens Camera (Ross)

the modern reflex camera was not envisaged by Sutton. A similar design in which the mirror was made to serve as a shutter was patented by Manerizzi of Trieste in 1884. C. R. Smith of London patented the same year what may be termed the first practical reflex camera.

The combination of two cameras, one to serve for focusing and arranging the image, the other for making the picture, appears to have originated with Desderi in 1864. Before the introduction of the reflex camera in the early years of this century, twin lens cameras of the type shown in Fig. 18 were popular despite their size and weight. Within recent years this type of camera has been revived in smaller sizes and is once more in general use.

The first hand camera designed exclusively for roll film was the Kodak of George Eastman which was placed on the market in 1888. It was a box camera (Fig. 19) making 100 pictures 2½ inches in diameter.

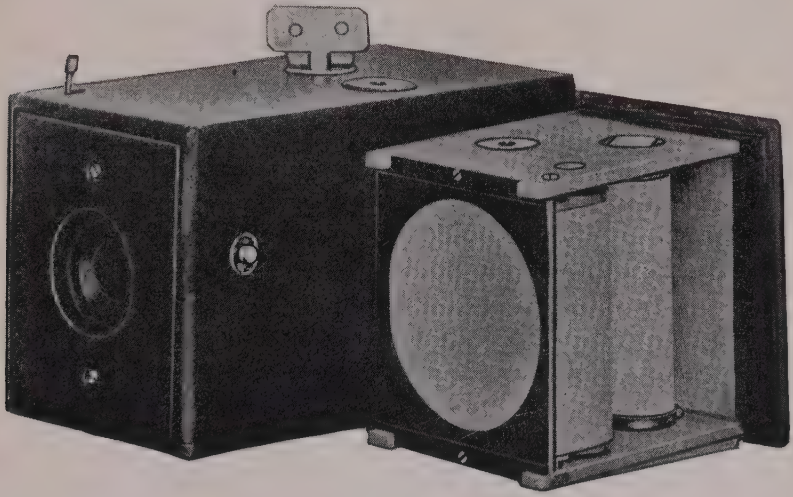

Fig. 19. Early Kodak

In 1913 Oskar Barnack, an engineer with the optical instrument firm of Ernst Leitz of Wetzlar, Germany, designed a small camera using thirty-five millimeter motion picture film and making pictures 1 × 1½ inches (24 × 36 mm.). This camera, after having been delayed by the World War, was introduced commercially in 1923 as the *Leica.* This camera embraced a number of new and useful features and was followed within a few years by others of similar design which have formed the basis of a new and active field of photography based upon the miniature camera.

The Development of the Photographic Objective.—The first lens used for photographic purposes appears to have been adapted by Chevalier, the well-known optician of Paris, from the Fraunhofer telescope objective which has the form shown in Fig. 20. The covering power of a lens of this construction is very limited, being about ⅓ of its focal length, and to secure good definition it must be used at a comparatively small aperture. An objective, presumably of this type, described by Daguerre in his book on the Daguerreotype process had a relative aperture of about F 15.

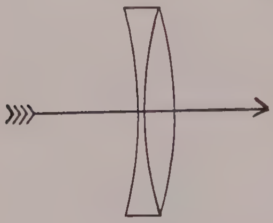

FIG. 20

In order to lessen the exposure required when using lenses of this type, Chevalier in 1840 designed a compound portrait lens (Fig. 21) which had a relative aperture of F 6.7. These lenses had a "chemical" focus, i.e. the focus for visual light and that for the photographic image did not coincide so that it was necessary to make a correction after focusing in order to obtain a sharp image.

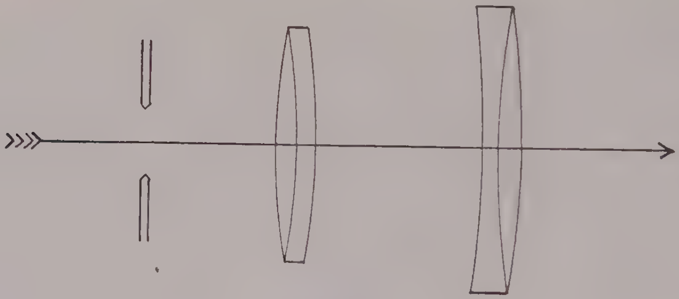

FIG. 21

This same year (1840) Voightlaender, of Brunswick, brought out a new lens which had been designed especially for photographic portraiture by Professor Joseph Petzval, of Vienna. This lens was excellently corrected for a small angular field and had an aperture of F 6

CLAY—The Photographic Lens from a Historical Point of View. Phot. J., 62 (1922), 459.

LEE—Development of the Photographic Lens. Glass Industry, II (1930), 199–203.

which was soon increased to F 4 by Andrew Ross, of London. In later years Dallmeyer of London and others made lenses of the Petzval type with apertures up to F 2.2. Petzval's first objective had a chemical focus; a decade later he recalculated the objective and eliminated the focal difference. The first lenses to have the visual and photographic foci coincident appear to be those of the Parisian optician Lerebours (1846) and Andrew Ross, of London (1848).

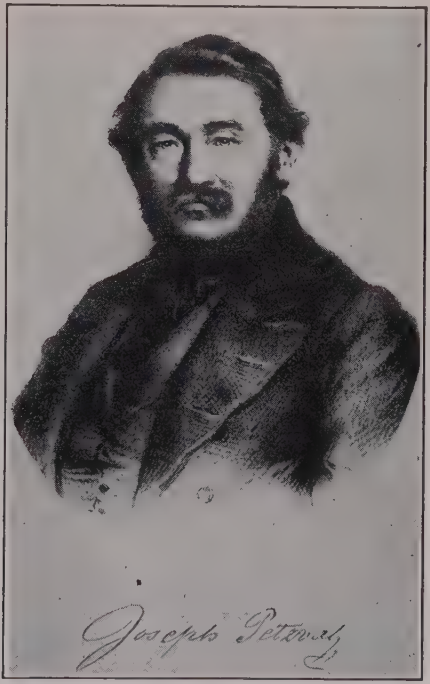

FIG. 22a. Josef Petzval

The Petzval portrait objective represents one of the greatest achievements in the history of the photographic objective. No other lens has played so important a part in the development of photography. So successful was the design that today nearly one hundred years later, the Petzval type of lens is still made and highly esteemed by portrait photographers.

For some years following the introduction of the Petzval lens the efforts of opticians were directed towards the development of a lens which would have a flat field and cover a wider angle. In 1841 Thomas Davidson designed a symmetrical objective which, however, was not a commercial success as it was put forward as a portrait lens and as such could not compete with the Petzval lens. Davidson, moreover, appears not to have realized the advantages of a symmetrical construction in reducing distortion and other aberrations for a wider field.

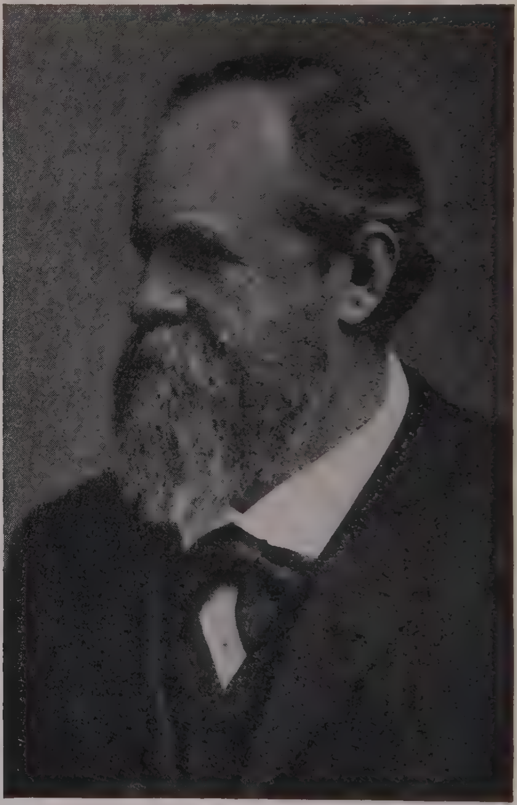

Fig. 22b. Adolph Steinheil

Wolcott, in the United States, designed a symmetrical lens in 1843, Fig. 23, and appears to have been the first to appreciate the advantages of the symmetrical design. His early death prevented the commercial development of his ideas. According to von Rohr, the eminent historian of the photographic objective, Wolcott of all of the early designers of photographic lenses came closest to Petzval's mark.[10]

In 1860 Harrison, of New York, introduced the globe lens, so called because the surfaces of the outer lenses form portions of a complete sphere. It was well corrected for distortion and covered a large field but was not well corrected spherically. A few years later Morrison, who had been an employee of Harrison, modified the globe lens by departing from a symmetrical arrangement. This, however, was not free from flare.

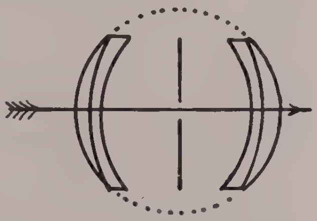

Fig. 23. Globe Lens of Harrison

In 1865 Steinheil, of Munich, introduced his Periscope designed especially as a wide angle objective. However, the corrections were poor, necessitating a small stop (F 30) and the visual and chemical foci did not coincide. Josef Zentmayer of Philadelphia improved on the Periscope by making it unsymmetrical, the back lens having a shorter focus than the front. A similar objective was patented by Boyle as the Ratio lens. This, however, does not appear to have reached the commercial stage.

Thomas Ross, of London, introduced in 1865 an improved form of his doublet lens (Fig. 24) which was moderately successful although it required a rather small diaphragm.

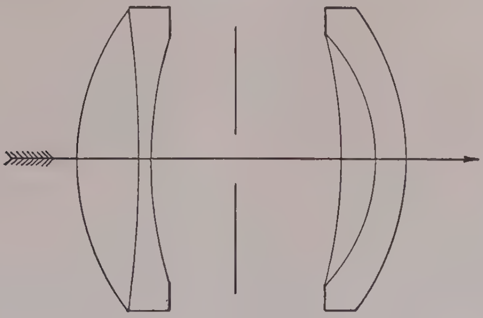

Fig. 24. Doublet of Ross

In the meantime various opticians had experimented with a so-called triplet construction. Thomas Ross made a simple triplet of three lenses for Fox-Talbot in 1841 and in 1860 Thomas Sutton took out an English patent for a symmetrical cemented triplet lens (Fig. 25). The first triplet construction to be placed upon the market, however, was introduced by Dallmeyer the same year (Fig. 26). This was quite popular for a number of years although it and the other lenses which we have described (except the portrait lens) were eclipsed by the aplanat of Steinheil and the rapid rectilinear of Dallmeyer which were introduced in 1866.

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[10] Von Rohr, *Phot. Jl.*, 74 (1924), 349.

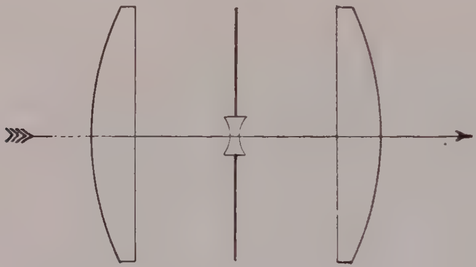

FIG. 25. Sutton Triplet

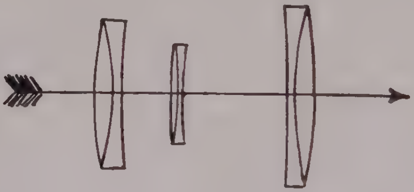

FIG. 26. Triple Achromat of Dallmeyer

The principle utilized in the aplanat and the rapid rectilinear was discovered independently by Steinheil and Dallmeyer and involved the use of two flint glasses of more nearly the same refractive index than the flint and crown glasses used in the earlier double lenses. This greatly reduced astigmatism and improved the correction for the other aberrations. It did not, however, permit the simultaneous removal of astigmatism and curvature of field. This was accomplished only after the introduction of the newer varieties of glass by the Jena Glass Works had made possible the *anastigmat*. The aplanat, or rapid rectilinear, as it is commonly termed in English speaking countries, represented a signal advance in photographic optics and is the only one of the lenses discussed thus far, with the exception of the Petzval portrait lens, to survive.

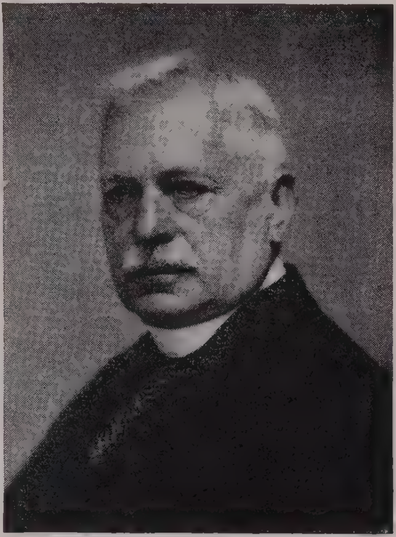

FIG. 27. Paul Rudolph, One of the Leaders in the Development of the Anastigmatic Objective.

The Antiplanat (Fig. 28), introduced by Steinheil in 1879, may be regarded as the immediate predecessor of the anastigmat. In this lens the symmetrical arrangement was departed from. The element in front of the diaphragm is positive and that in the rear is negative in effect, although only to a slight extent. Thus by compensating for the errors of one element by errors of the opposite character in the element on the other side of the diaphragm, Steinheil was able to improve the correction for astigmatism and at a larger aperture than had been possible with the aplanat. The Antiplanat, despite the great originality displayed in its design, was soon superseded by the anastigmats which made their appearance almost exactly ten years later (1890).

The first lens in which the new Jena glasses were used to produce an objective free from astigmatism and with a flat field was calculated by Schroeder and introduced by Ross Ltd., of London, in 1888 as the Concentric (Fig. 29). It was not well corrected spherically, requir-

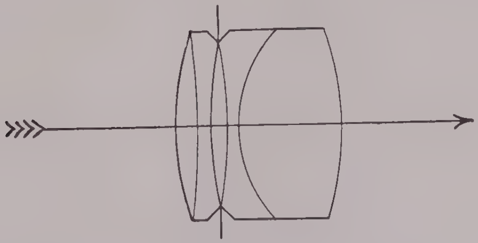

FIG. 28. Antiplanat of Steinheil

ing a small stop to obtain good definition, and was soon withdrawn. The first objective in which adequate correction for spherical aberration and astigmatism were combined with a flat field was patented by Paul Rudolph, of Jena, and introduced in 1890 by Carl Zeiss as the Protar.

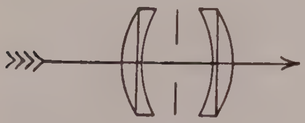
FIG. 29. Coincentric Lens of Schroeder and Ross

Since that time the development of the anastigmatic objective has followed along five more or less well defined lines: (1) symmetrical objectives based on the aplanat (rapid rectilinear) but employing the new Jena glasses to produce an objective whose elements are individually corrected for use alone (*Dagor, Protar, Collinear,* etc.), (2) unsymmetrical objectives following the principle employed in the Antiplanat of Steinheil (*Tessar,* etc.), (3) the triplet construction of H. D. Taylor (Cooke lens) and his followers (*Cooke, Heliar, Aviar* etc.), (4) the so-called Gaussian objective based in part upon the method developed by Gauss for the correction of telescope objectives (*Planar, Aristostigmat, Homocentric, Biotar, Opic,* etc.) and (5) the Steinheil construction, an original design developed by Rudolph Steinheil in 1901 (*Unofocal,* etc.). Since these lenses, or modifications of them, are all in use today, it is more convenient to discuss their development and design in Chapter 4, The Photographic Objective.

The earliest photographic application of a rear negative element to a photographic objective in order to form a telephoto objective appears to be due to J. Porro in 1851. It received little or no attention, however, and the telephoto lens was really developed by Steinheil, of Munich, and Dallmeyer, of London. The latter took out a British patent in 1890 for a compound telephoto objective which consisted of a well corrected photographic lens and a back negative element composed of two achromatic lenses; as the distance between the two was variable a wide range of magnification was possible.

Strictly speaking, the first fixed magnification telephoto objective was the Orthoscope, designed by Petzval in 1840 or 1841 although not placed on the market until 1857. It consisted of two elements (Fig. 30) separated by the diaphragm. The front element is similar to that of the Petzval portrait lens and is positive: the rear element is negative and enlarges the image formed by the front lens. Little or no attention seems to have been paid to this characteristic of the Orthoscope lens and it disappeared from the market with the advent of the aplanat. It was not until 1905 that the first of the modern fixed magnification telephoto objectives was introduced; the Bis-Telar of Emil Busch. This was designed by K. Martin and had a relative aperture of F 9 and a magnification of 2. The following year Zeiss brought out the Magnar which had a relative aperture of F 10 and a magnification of 3. Similar objectives but with improved astigmatic correction and of larger apertures were designed in 1912 by Hasselkus, of Ross Ltd., and two years later by Lan Davis, of Dallmeyer Ltd., both of London. The first was introduced as the *Telecentric* in two series, one with a relative aperture of F 5.4 and the other F 6.8. The second was placed on the market as the *Large Adon* and had an aperture of F 4.5.

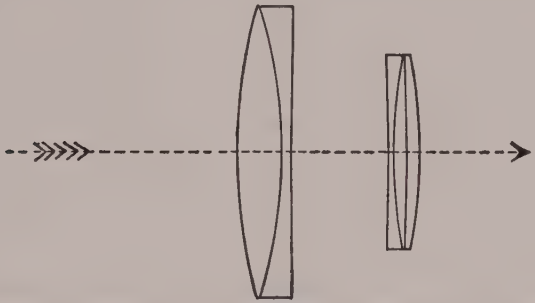

FIG. 30. Petzval's Orthoscope—A Predecessor of the Fixed Magnification Telephoto Lens

Fixed magnification telephoto objectives introduced since 1914 will be discussed in Chapter 4, The Photographic Objective.

Color Photography.—Methods of producing photographs in natural colors may be divided into two classes, (1) *direct,* depending upon the bleaching of light sensitive dyes or light interference and (2) *indirect.*

Direct Processes of Color Photography.—Seebeck in 1810 found that silver chloride when exposed to the rays of light partook slightly of the colors themselves and Edmond Becqueret in 1844 reproduced more or less perfectly the seven principal colors of the spectrum on a Daguerreotype plate. The colors were lost, however, when the plate was fixed. Similar processes were described by Herschel, Niepce de Saint Victor and Robert Hunt.

LEE—Development of the Telephotographic Objective. Proc. Opt. Conv., 1926, 869–877.

In 1897 Lippman of Paris described a process of natural color photography based upon the principle of light interference. A grainless albumen film was exposed in front of a mirror, formed by a bath of liquid mercury, developed and fixed in a weak solution of cyanide resulting in a brilliantly colored image when viewed by light reflected from a mirror. The results, however, cannot be duplicated, the process is slow and tedious, and natural colors are not well reproduced hence the process remains no more than an interesting demonstration.

Indirect Processes of Natural Color Photography.—Promising as such processes of natural color photography may appear theoretically, it is with indirect methods involving the separate registration of the three fundamental color sensations and their subsequent recombination that the greatest progress has been made.

The first to apply such methods was James Clerk Maxwell, of the Royal Institution in London, who in 1861 took three photographs, one through a red solution acting as a color filter, one through a green solution, and a third through blue-violet. From these negatives he had lantern slides made which he projected on top of one another by means of three lanterns; each one projecting its slide through the solution which had been used in making the original negative. The result was not wholly successful (1) because the wet-collodion process was almost insensitive to green and red, and (2) because the solutions employed did not have the proper spectral transmissions.

In 1862, Louis Ducos du Hauron deposited with the French Academy of Sciences a paper on processes of color photography which, however, was not presented to the Society nor was it published until 1897. In the meanwhile, he published (1869) *Les Coleurs en Photographie, Solution du Probleme* in which he described (1) a tri-color camera for making three-color negatives with one exposure, (2) combining positives on glass from the three negatives in a viewing device similar to the camera to produce an image in colors, (3) printing from three-color negatives by the carbon process to produce a print in colors, and (4) the screen plate process.

In 1895, he patented a tri-pack, the three plates being placed together with their respective filters in between, thus enabling the three negatives to be made with one exposure in an ordinary camera.

While all subsequent progress in color photography has been along these lines, du Hauron was unable to perfect any of these methods owing to the limited sensitivity of the negative materials then available and to his limited financial resources.

Three-color cameras and viewing instruments were brought to a high degree of perfection by F. E. Ives of Philadelphia, who during his long association with color photography added greatly to our store of knowledge of all processes (except the screen-plate). Space does not permit an extended treatment of the history of tri-color cameras nor viewing instruments (photo-chromoscopes). An excellent survey of the various types is available in the *History of Three-Color Photography* by E. J. Wall (Boston, 1925).

A number of tri-packs have been patented and several have reached the commercial stage, but only in recent years has a reasonably successful product been achieved.

Subtractive Printing Processes.—Since du Hauron first suggested the carbon process as a means of making the three-color images required by subtractive printing processes, many other methods have been exploited. These include the production of dye images (1) by mordanting methods, (2) differentially hardened gelatine, (3) gelatine relief images, (4) imbibition processes based upon the transference of dyes from gelatine printing plates produced by methods 2 or 3, (5) toning of silver images with metallic compounds, (6) pigment processes such as carbon, gum-bichromate and, more recently, three-color carbro, (7) developers producing color images and (8) processes employing diazo dyes.[11]

Screen Plate Processes.—In just the same way that a painter may secure a certain color by the juxtaposition of dabs of pigment of two colors which when viewed at a distance merge to form a single color, so it is possible to secure on a single plate all three color-sensation records by employing, in place of the usual solid color filter, a multicolor screen composed of a large number of small color screens evenly distributed and so small as to be practically invisible.

The multi-color screen was the conception of Louis Ducos du Hauron whose patent of 1868 suggested that a sensitive plate be exposed behind a screen composed of fine parallel lines, red, green and blue. The red lines collectively record the red sensation of the subject, while in like manner the green and blue lines collectively record the green and blue sensations respectively, so that all three fundamental color records are secured on a single plate. Consequently when a positive from the original negative is placed in contact with the multicolor screen in the position occupied by the negative, so that the lines in the positive recording the red sensation are behind the red lines of the multi-color screen, the colors of the subject become visible, the same principle being brought into play as in the viewing camera.

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[11] Crabtree, U. S. P. 1389742; Traube, D. R. P. 187289 of 1905; Kelley, 1411968 of 1922.

Howard Farmer, B. P. 17773 of 1889; Capstaff, B. P. 13429 of 1915.

Senninger, Shepard & Bartlett, B. P. 24234 of 1902.

Didier, B. P. 7557 of 1905.

Hamburger, *Brit. J. Phot.*, **58** (1911), 39.

Manley, B. P. 10026 of 1898; *Brit. J. Phot.*, **46** (1899), 198.

It was not until 1894, however, that the first practical screen plate was produced by Joly, of Dublin. The screen consisted of parallel red, green, and blue lines each 1/100 inch wide and was placed in front of a panchromatic material for the exposure. The plate was developed and a glass transparency made in the usual way. Finally, this transparency was bound up in register with a screen plate similar to that used in making the negative so that an image in natural color was produced.

MacDonough of Chicago succeeded a year or so later in making a finer screen (300 to the inch) which, however, was not successful commercially owing to the high cost of production.

Various methods of making multi-color screens were patented by Brasseur (1896), Powrie of Chicago (1905), Smith (1906), Krayn (1906), Dufay (1908) and Lumière (1904). Of these only one was immediately successful, the *Autochrom* plate of Lumière, a mosaic screen composed of dyed starch grains which was placed on the market in 1907. A similar plate in which dyed gum particles rather than starch grains are used was patented by Christensen in 1916 and introduced as the *Agfa Color Plate* in 1921.

In 1906, C. L. Finlay patented a screen plate which was placed upon the market as the "Thames" plate. This plate had a geometrical pattern consisting of two separate sets of circles on a background which formed the third color-record. The Thames plate was not a success, but a similar screen known as the *Finlay* plate, introduced in 1930, has been well received.

A separate screen plate process was introduced by the Paget Dry Plate Company of London in 1908 utilizing the patents of Whitfield. This process was the most successful commercially of the earlier separate screen processes and remained on the market for a number of years.

In 1908, Dufay patented a method of making a screen-plate of geometrical design, which was placed on the market as the *Dioptichrome*. This remained on the market for several years. In 1935, an improved process with a finer screen and greater exposure speed was placed upon the market as *Dufaycolor.*

In 1908, Berthion of France patented a variation of the screen plate process in which the film is embossed so as to form minute elementary lenses and a three-color banded filter is placed over the camera lens. An image of the subject is formed on the film in the usual manner but the embossed lenses on the front side of the film (Fig. 31) break the image up into minute images of the three-color filter. A screen formed in this manner is termed a lenticular screen. In 1928, the rights to the Berthion patents were acquired by the Eastman Kodak Company and utilized in a process of amateur cinematography known as *Kodacolor.*

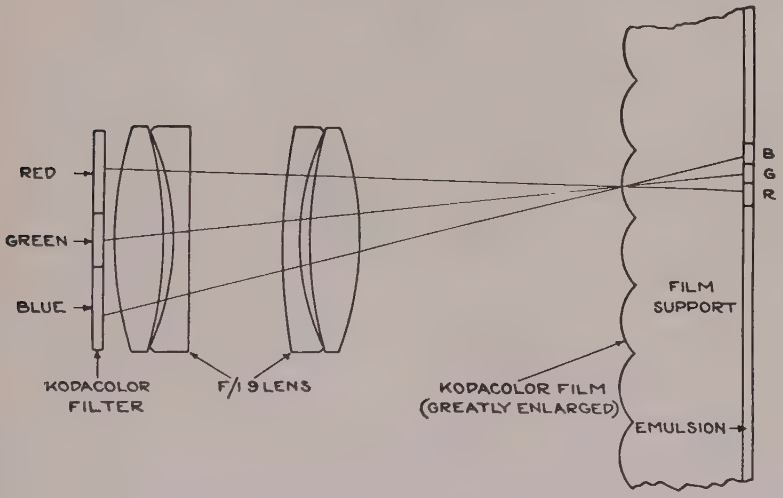

FIG. 31. Diagram of Kodacolor Process

A notable advance in color photography was made in 1935 when the Eastman Kodak Company introduced Kodachrome. This is a three-color subtractive process which is unique in the fact that, instead of three separate negatives, three emulsions are coated on the film support one over the other and each is separately sensitized (Fig. 32) so that the blue-sensation record is made by the first emulsion, the green record by the second and the red by the third. In processing these images are first converted into direct positive images in silver and these in turn are converted into dye images, the dye images of course being complementary to the colors of the original negative images. In this way, a color transparency is produced in which the different color records are in three layers which, however, are so thin and close together that they have the same effect as a single layer. First employed for amateur cinematography, Kodachrome film and projectors are now available for still camera work.

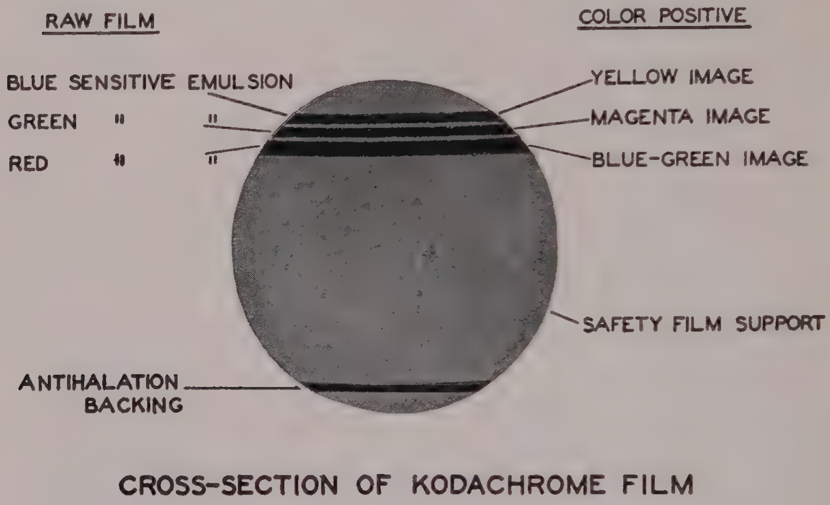

Fig. 32. Cross-Section of Kodachrome Film. (Eastman Kodak Co.)

CHAPTER II

THE CAMERA

Elements of the Camera

The essentials of the camera are four in number: (1) a light-tight enclosure; (2) a means of forming an image either by means of a pinhole or a lens; (3) a holder for the sensitive material and (4) a means of controlling the time during which light is allowed to reach the film or plate (shutter).

The simplest box camera, in addition to these essentials, is provided with a *finder* to show what will be included in the picture, a *diaphragm* to regulate the amount of light entering the lens, and a means of changing the film or plate between exposures. Other types of cameras may have a *collapsible bellows,* or a metal tube operated either by a sliding or helical motion, and a *focusing scale* or *screen* in order that the position of the lens may be altered so as to secure a sharp image of objects at different distances from the camera. It may have in addition a *range finder* to measure the distance of the object, *negative carriers* for different types of sensitive material, a *level, depth of focus scale,* built-in exposure meter, and various movements to the front and back which alter the position of the lens or the sensitive material in relation to one another.

Carriers for the Sensitive Material.—In roll film cameras, the film is drawn over rollers through the exposure plane to a take-up spool operated by a ratchet key which will turn in one direction only. Tension, created by a retaining spring on the film spool and a pressure pad in the image plane, keeps the film flat for the exposure. Numbers placed on the paper backing of the film spool and viewed through a red window in the back of the camera indicate the position of the film for the different exposures.

In cameras employing perforated film, the film is drawn through the exposure plane by means of a sprocket wheel which engages the perforations along the side of the film. An automatic stop permits the sprocket wheel to turn only sufficiently to position the film for the next exposure. It must then be disengaged to enable the film to be moved for the next exposure. In this way each image is automatically positioned in the film without requiring the attention of the operator.

On small cameras designed for cut film, plates, or film packs in an adapter, the focusing screen is contained within a panel which is interchangeable with the film or plate holder. Thus, the focusing screen must be removed to insert the holder. On American cameras of this type, the panel containing the focusing screen is attached to the back of the camera with springs so that the holder may be inserted in the position normally occupied by the focusing screen without the necessity of removing the latter.

The typical single metal cut film and plate holder is shown in Fig. 33. A pressure plate behind the hinged metal frame makes the holder suitable for both cut film and plates.

The typical American style double holder is shown in Fig. 34. Lifting up the hinged flap at the bottom allows cut film to be slipped in the grooves along each side of the holder. Glass plates are held in position by overlapping portions of the flap and the stays at the top of the holder.

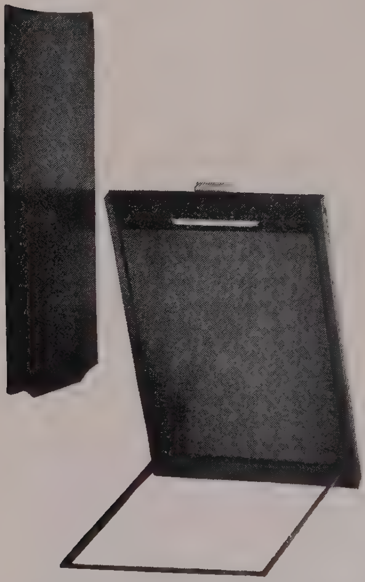

Fig. 33. Foreign Style Single Metal Plate and Cut-Film Holder (Kodak)

Focusing.—In box and other fixed focus cameras, no provision is made for focusing. A lens of comparatively short focal length and small relative aperture is used so that the depth of field is considerable and under these conditions it is possible to fix the lens permanently in a position which will result in satisfactory definition on all objects not too close to the camera. Focusing, however, is necessary if a large aperture lens is to be used effectively. The proper focus is determined (1) from an inspection of the image on a ground glass focusing screen, (2) by estimating, or (3) measuring by means of a range finder, the distance of the subject and setting the lens to a corresponding point on a scale of distances constituting a focusing scale.

The lens adjustment is made in one of several ways:

1. By moving either the front or back of the camera.
2. By moving the lens and shutter alone on a track or helical mount which forms a part of the camera front.
3. By revolving the front element of the lens.

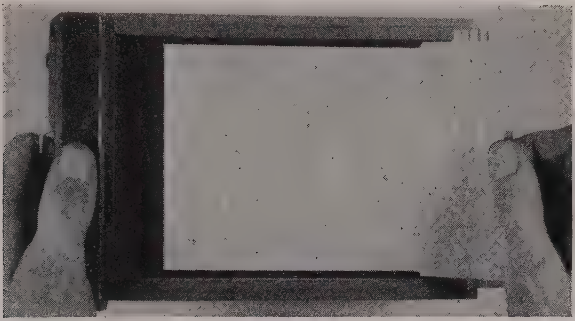

FIG. 34. American Type Cut Film Holder Showing Method of Loading

The first method is the only feasible one for large cameras and is used exclusively on professional view or studio cameras; the other methods are used chiefly on small hand and miniature cameras.

In a number of modern cameras, a range-finder, or distance meter, is directly connected to the lens so that the lens is focused in the operation of determining the distance of the subject.

Finders.—The finder is a very important feature of hand cameras since it provides the only means of knowing what will be included in the picture. The first requirement of a finder is that it should indicate exactly the area included by the lens of the camera. This is possible for all distances of the subject only if the axis of the finder and the lens coincide, a condition which is obviously impossible except in a reflex camera where the camera lens is used as a finder.

In designing a camera, the errors resulting from the separation of the finder and the lens are kept as small as possible by placing the finder as close to the lens and by making the axis of the one intersect with that of the other at a distance of approximately 15 feet. The difference in finder and lens image is then insignificant except on nearby subjects. In some cases, the field of the finder is made smaller than that of the lens so that all of the image seen in the finder will be included in the negative regardless of the distance of the subject.

The simplest form of reflecting finder consists essentially of a miniature box camera as shown in Fig. 35 with a mirror placed at an angle of 45° behind the biconvex lens to reflect the image to the ground glass screen. The so-called "brilliant" finder is similar (Fig. 35b) except that the ground glass screen is replaced by a second lens which results in a clearer and more brilliant image since the light is not scattered by the ground glass.

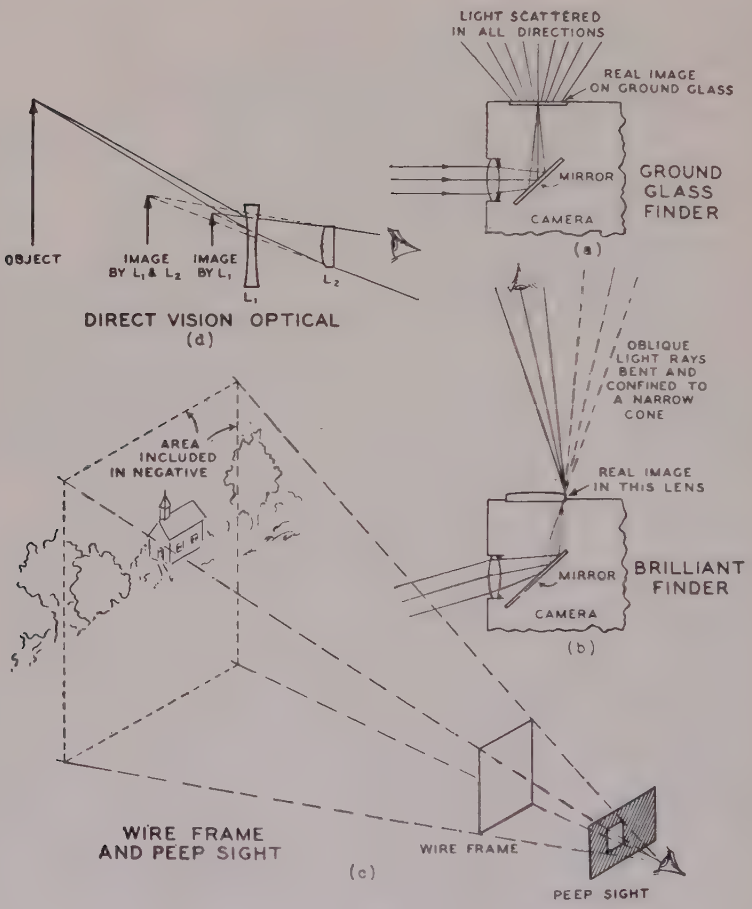

FIG. 35. Finder Systems

In all reflecting finders, the image is erect, but reversed laterally, i.e., from right to left. This is true also of the image seen on the focusing screen of a reflex or twin-lens camera.

Direct vision finders are of several types. One of the simplest is known as the wire-frame, or iconometer, finder. It consists of a metal frame corresponding to the picture size and a deep-sight; the first mentioned is placed in the same plane as the lens and the latter in that of the plate or film.

In some cases, the front frame is made considerably smaller than the picture area and its distance from the peep-sight reduced so that the angle included will correspond with that of the camera lens. This enables the finder to be placed on the side of the camera.

In still another type of direct vision finder (Fig. 35d), the front frame consists of a negative lens which forms a virtual image of the subject. The size and power of the lens determines the size of the field included in the finder.

Today, in finders of this type, the peep-sight is usually a low-power positive lens which projects the virtual image formed by the negative lens to a more comfortable viewing distance from the eye. This optical system results in an image which is not only erect but is also not reversed from right to left. Finders of this construction are very common on current miniature cameras.

SHUTTERS

Modern shutters may be divided into four classes; (1) those placed before the lens, (2) those placed behind the lens, (3) those placed between the lens and (4) those placed near the focal plane directly in front of the sensitive material.

Before-the-Lens Shutters.—Before-the-lens shutters are used on box and other cameras fitted with single lenses. Those used on box, and other inexpensive cameras, consist essentially of a thin metal disk with an open slot which is made to pass in front of the lens by a spring. This type of shutter is adjustable for time, for bulb, and a single "instantaneous" speed which may vary from 1/20 to 1/30 second depending upon the camera.

While placed before the lens, the shutters on folding cameras fitted with single lenses have more in common with the between the lens shutters to be described later.

On larger cameras, the before-the-lens shutter is virtually obsolete except for a single type used by professional photographers. This is similar to the modern between-the-lens shutter except that it has no marked instantaneous speeds and is mounted so as to be readily attached to the front of the lens mount thus permitting it to be used on a number of different lenses.

Behind-the-Lens Shutters.—Behind-the-lens shutters are used chiefly on professional view, commercial or portrait cameras. One type, now nearly obsolete, consists of one, or in some cases two, metal leaves which operate in the same manner as a door. The two leaves are kept in the closed position by means of a spring. The exposure is made by means of a bulb and tubing which compresses the air within a cylinder and operates a piston causing the leaves to swing open and uncover the lens. While this type of shutter is not suitable for extremely short exposures, it can be made almost noiseless in operation which is an advantage in portrait work.

By far the most widely used behind-the-lens shutter consists of two, or in some cases three, metal, hard rubber or plastic blades which are kept overlapping in the closed position by means of a spring. Compression of the air within a cylinder operates a piston which causes the blades of the shutter to make a partial revolution about pivoted points thus uncovering the lens. Upon releasing the pressure on the bulb, the spring tension causes the blades of the shutter to move in the opposite direction thus closing the opening. This type of shutter is more compact than the type previously described and is better adapted to short exposures. With some models, exposures of approximately 1/25 second are possible.

Between-the-Lens Shutters.—Between-the-lens shutters are frequently referred to as diaphragm shutters because of their location near the diaphragm. In some cases, the blades of the shutter are made to serve as a diaphragm opening up only to the set value.

The modern between-the-lens shutters consist of three, or more, thin, hard-rubber, metal or composition blades which are pivoted about fixed points in a circle. These blades are opened and closed by pins on a movable ring. A spring provides the motive power to move this ring through a portion of one revolution. Usually the blades open and close at a fixed speed which is governed by the tension created by the driving spring. The time which the blades remain open is controlled either by pneumatic action or by a series of retarding gears. The former consists essentially of a cylinder and piston, the air being either compressed or partially exhausted in the setting of the shutter. An adjustable leak, which is controlled by the speed setting on the shutter dial, delays the action of the spring on the inner movable ring controlling the shutter blades and thus fixes the time during which the lens is uncovered. In gear-controlled shutters, a chain of gears with an escapement somewhat similar to that on a watch is employed to delay the closing of the shutter blades until the desired time has elapsed.

Focal Plane Shutters.—The focal plane shutter is so termed because it is placed near the focal plane, immediately in front of the sensitive material. Shutters of this type are used on reflex cameras and on many miniature cameras. While reflex cameras have been designed with other types of shutters, the focal plane shutter is particularly suitable since it operates behind the mirror thus enabling the lens to remain open at all times for observing the image and focusing. (See Reflex Camera). On miniature cameras it enables different lenses to be used without having a separate shutter for each and in addition the operation of resetting the shutter and the movement of the film may be so connected as to prevent double exposures.

There are two variations of the focal plane shutter; (1) the fixed and (2) the variable slit. The first consists of a relatively long opaque curtain of cloth, or other suitable material, running between a pair of rollers on opposite sides of the picture area, one of the rollers being under tension. The curtain is slightly wider than the picture and the edges are enclosed in grooves which serve the double purpose of forming a guide for the passage of the curtain from one roller to the other and protecting the sensitive material from light. Across this curtain, at distances slightly greater than that between the two rollers are a number of slits of varying widths.

Preparatory to making an exposure, the shutter is set by winding the curtain so as to select a slit of the proper width and the spring tension on the lower roller is adjusted so as to regulate the speed at which the open slit passes in front of the film or plate. These adjustments are made in accordance with a table affixed in a convenient place on the outside of the shutter indicating the width of the slit and tension setting for a given exposure. When the shutter is set, the plate or film is protected by an opaque portion of the curtain. Upon releasing the exposure lever, the curtain is freed and the tension on one of the rollers, usually the lower, causes it to revolve, winding the curtain on it so that the slit passes rapidly in front of the sensitive material thus making the exposure. A locking device stops the curtain after the slit has passed in front of the film or plate thus preventing a second exposure.

The variable slit shutter differs from that just described in having two curtains, one directly in front and as close to the other as practical and each has its own pair of rollers. Springs attached to one set of rollers, usually the lower, keep the curtains under tension. Each curtain may be wound up separately but both move downward across the face of the film or plate at the same rate when freed by the exposure lever. The height of the slit in one of the curtains is approximately the same as that of the picture.

Before making an exposure this curtain is wound up on the free roller. The second curtain, however, is only partially wound up. Consequently, it does not completely cover the slit in the first curtain but leaves an open slit the height of which can be varied as required by the extent to which the second curtain is wound up. Thus the width of the opening between the two curtains may be varied at will, so as to control the amount of light reaching the film and thus determine the exposure.

This type of shutter is rather more complicated than the other but has the advantage that a wide range of exposures may be obtained by varying the width of the slit, thus rendering less necessary the dependence upon variations in spring tension as a means of controlling the exposure. Furthermore, a shutter of this type may be graduated to read directly in terms of exposure and is the only type really practical for miniature cameras.

On reflex cameras the mirror protects the film or plate from light when the shutter is wound up to make an exposure. In other types of cameras with a focal plane shutter the exposure of the sensitive material is prevented by an auxiliary curtain placed in front of the shutter. This protecting curtain is wound up first and released after the shutter has been set. Such shutters are frequently termed "self-capping" since it is not necessary to cover the lens to prevent the exposure of the film or plate when setting the shutter.

With a focal plane shutter, unlike those placed near the lens, the entire image is not exposed simultaneously but successively in sections from one side to the other as the opening in the curtain passes across the face of the sensitive material. This being the case, it is evident that the image of a rapidly moving object will be distorted through movement of the image during the exposure. Such distortion commonly takes the form of elongated or compressed images, diagonally deformed; for example, wheels on rapidly moving motor cars, curved spokes in the wheels of rapidly moving machinery etc. With a horizontally moving curtain, the image is lengthened if the slit moves in the direction of the image; that is, in the opposite direction to the subject: compressed, if the slit moves in the opposite direction.

There is some variation in exposure from one side of the image to the other, due to the fact that the velocity of the curtain, starting from rest at one side of the image, increases as it passes over the film or plate until it reaches the opposite side. In well-designed shutters, however, retarding devices prevent this variation in speed from being sufficient to produce any preciptible difference in exposure.

Speed and Efficiency of Shutters.—The *speed,* or *exposure time,* of a shutter is the time interval during which light is admitted. In a between-the-lens shutter it is the time elapsing between the opening and closing of the shutter blades; in a focal plane shutter it is the time required for the slit in the curtain to pass a given spot on the sensitive material.

The *efficiency* of a shutter may be defined as the *ratio* between the amount of light actually reaching the sensitive material and the maximum amount which can be admitted in the same period of exposure. A between-the-lens shutter, whose blades opened instantaneously to the maximum opening and remained open for the full period of the exposure and then closed instantaneously would have an efficiency of 100 per cent. No existing shutter approaches 100 per cent efficiency. Between-the-lens shutters vary in efficiency depending upon the number of blades employed and other details of design. In general, the larger the number of blades employed the higher the efficiency of the shutter and in this respect modern between-the-lens shutters are greatly superior to older and simpler types. With the latter, the efficiency may be as low as 50 per cent; with the best modern shutters it varies from 70 to 80 per cent. Since the blades of a diaphragm shutter are at their maximum opening for only a part of the total exposure time, it is evident that if the aperture of the lens is less than the maximum opening of the shutter, the longer will be the period during which the lens is fully uncovered and consequently the greater the efficiency of the shutter. Thus stopping down the lens, or mounting it in an oversize shutter, has the effect of improving the efficiency of the shutter!

While in general, the efficiency of focal plane shutters is higher than diaphragm shutters the difference is not considerable if modern types of between-the-lens shutters are used as a basis of comparison.

Were it possible to have the curtain of a focal plane shutter in actual contact with the film or a plate, an efficiency of 100 per cent could be attained but this condition is manifestly impractical. The efficiency diminishes rapidly as the distance between the curtain and the film is increased and as the width of the slit is decreased. As with a between-the-lens shutter the efficiency decreases as the aperture of the lens increases.

High efficiency in a shutter is naturally most important with short exposures since with these it is frequently difficult to avoid underexposure. Unfortunately, the efficiency of both focal plane and between-the-lens shutters becomes lower at the shorter exposures. With a focal plane shutter, the maximum efficiency at high speeds will be obtained by using as wide a slit and as high a spring tension as possible rather than a narrow slit at a lower tension.

Swing Back.—The swing back is a movement, found quite generally on professional cameras and occasionally on film and plate cameras designed for the serious amateur, which permits the plane of the sensitive material to be placed at an angle to the optical axis of the lens, for the purpose of (a) changing the shape of the image, or (b) securing greater depth of field.

When the plane of the sensitive material is parallel with that of the subject, parallel lines in the subject are rendered parallel on the image. If, however, the plane of the sensitive material is inclined towards that of the subject, as in Fig. 36, the image is distorted and the lines diverge. Tilting the sensitive material in the other direction causes the lines to diverge but in the opposite direction. Inclining the plane of the subject would produce precisely the same result.

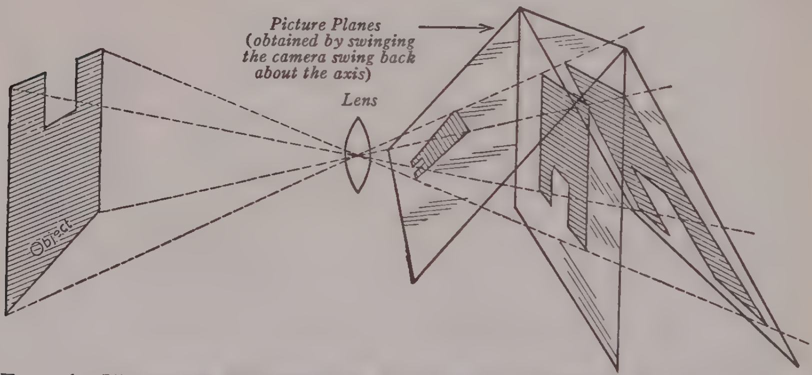
Picture Planes
(obtained by swinging the camera swing back about the axis)
Lens
Object

Fig. 36. Illustrating the Effect on the Image of Inclining the Plane of the Sensitive Material to That of the Subject

In photographing a tall building, for example, it is frequently necessary to tilt the camera in order to include all of the building. With the sensitive material in its normal plane, that is at right angles to the camera axis, the lines of the building converge towards the top. The swing back, however, enables the sensitive material to be placed in the vertical position, thus securing non-distorted rendering.

In photographing from an elevation, the same principle applies except that the conditions are reversed.

Since the axis of the lens is no longer at right angles to the sensitive material, but crosses it obliquely, a smaller diaphragm is usually necessary to obtain sharp focus over the whole of the image.

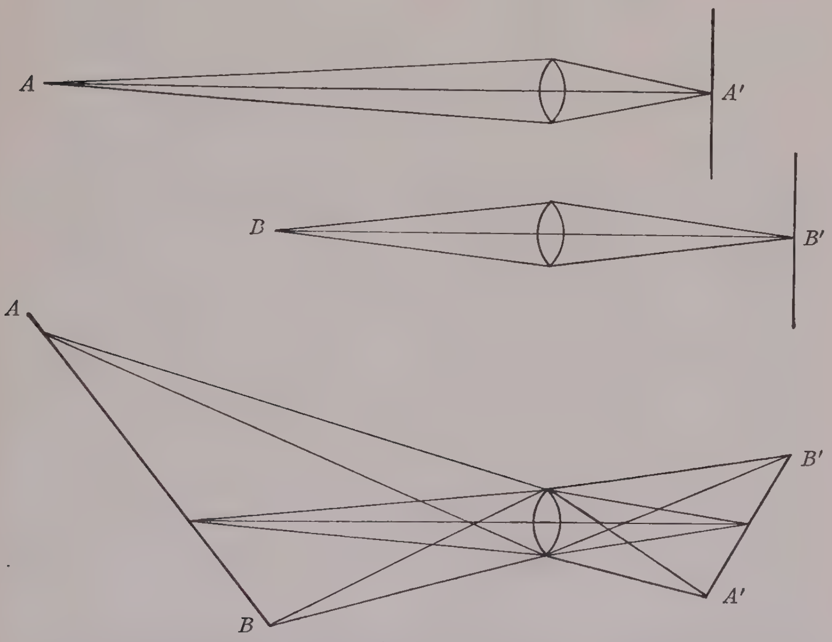

FIG. 37. Illustrating How the Swing Back is Used to Increase the Depth of Field, (Upper) the Focal Plane for Objects at a Distance, (Middle) the Focal Plane for a Nearer Object, (Lower) How Both Objects may be Sharply Rendered by Including the Sensitive Material in the Direction Shown.

Since it is clear from the principles of image formation that the focal distance for near objects is greater than for more distant objects, it is possible under certain conditions to secure sharp focus on both near and distant objects with a relatively large aperture by the simple expedient of inclining the sensitive material. The principle involved is shown diagrammatically in Fig. 37.

A and *B* represent two objects at different distances from the lens and *A′* and *B′* the corresponding image points. It is evident that with the sensitive material at right angles to the optical axis, there is no point at which the image of both *A* and *B* will be sharp, and only by placing the sensitive material between *A′* and *B′* and using a small diaphragm can a sharp image of both be obtained. If, however, the sensitive material is inclined as indicated by the line *A′B′*, both points will be sharply rendered.

It is obvious that the swing back may be used in this manner to increase the effective depth of field only if points *A* and *B* lie at some distance above one another. This, however, is frequently the case in practice, as for example, with a group of persons arranged in rows behind one another in a staircase formation, a banquet table, a street photographed from an elevation, etc.

A horizontal swing back may be used in the same way when photographing objects at different distances, on a horizontal rather than a vertical plane. When necessary, both the vertical and horizontal swings may be used in conjunction.

The use of the swings in this manner distorts the perspective since the relative size of near objects is increased and the height decreased. This distortion is in many cases immaterial and in some an advantage. When objectionable, it can be partially rectified in projection printing (See, Correction of Distortion in Projection Printing).

The Swing Front.—The swing front is an adjustment enabling the lens to be tilted upwards or downwards so as to change the angle of the optical axis with respect to the sensitive material. It is a movement which is found on few cameras except those designed for difficult work of a technical nature.

The swing front may be used in much the same way as the swing back to increase the effective depth of field but with the advantage that the perspective is not distorted to the same degree. It is useful also in avoiding the necessity for a small diaphragm when the swing back is used to keep the sensitive material vertical. When, for example, the camera is inclined upward to include the top of a tall building, and the swing back is placed in a vertical position, a small diaphragm is often required to render both the top and bottom of the building sharp. If, however, the camera is fitted with a swing front, the use of a small diaphragm may be avoided by inclining the lens so that its optical axis is approximately parallel to the sensitive material.

The use of the swing front in any case is practical only when the lens will cover sharply a picture area larger than that on which it is being used.

Photographing Object with Front Square and at Same Time Showing Side or Top.—Manufacturers sometimes request photographs which show the front of the article square and at the same time reveal a part of the side or top. Books, packaged articles, radio cabinets, etc., are frequently represented in this manner.

This effect is produced by setting up the camera from a position which will include a small portion of the top, or side, of the object, and adjusting the swings so as to be parallel to the front of the object in both directions. In this way, the front of the object is represented as square although actually it was at angle to the lens at the time the picture was made.

Generally speaking, the adjustments of ordinary view cameras are not sufficient for such work unless one is content with a small image. Commercial cameras having both a swing front and swing back, however, are suitable.

Sliding Front.—This movement allows the lens to be moved in a horizontal direction parallel to the film or plate. On hand cameras not fitted with a reversible back, it serves as a rising and falling front, when the camera is placed on its side to make a horizontal picture. On cameras designed for professional use, it is frequently useful in obtaining unusual viewpoints and in distorting perspective to secure striking effects. Like all such movements, it presupposes the use of a lens with greater covering power than the plate or film with which it is used.

Box Camera.—The inexpensive box camera is used chiefly by beginners or by those who are interested in photography only to the extent of making record pictures with the least expenditure of thought and energy. The box camera of today is usually designed for roll film as film pack and plate models have practically disappeared in this country. American cameras of this type are usually fitted with single lenses having a maximum relative aperture of about f :14 and a simple spring-actuated shutter with one instantaneous speed of about 1/25 second in addition to time and bulb. Even these last are omitted on some cameras. Ordinarily no provision is made for focusing, the position of the lens being fixed so that objects not less than 6 to 10 feet, depending on the size of the camera, will be sharp. In recent years, however, cameras with two lenses, one removable, have been introduced. Both lenses together are used for nearby objects and the rear lens alone for distant subjects. In a more expensive form of the box camera, the lens mount revolves, thus changing the separation of the two elements and providing for focusing for three marked positions, near, medium, distant.

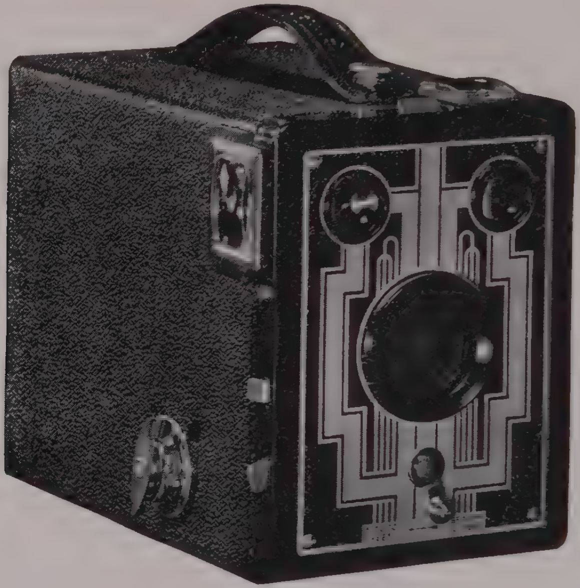

FIG. 38. Box Camera for Roll Film. (Eastman Kodak Co.)

Cameras of this type reduce picture making to its simplest terms. It is only necessary to exercise the modicum of care and attention to secure good results within the rather limited scope of the camera.

Folding Roll Film Cameras.—Folding roll film cameras are perhaps the most popular among amateurs particularly with those whose interest in photography lies chiefly in making records of activities and scenes in which they are interested. A camera of this type, while larger than a miniature camera, is easily carried in the hand, the coat pocket, or on a shoulder strap, and has the advantage that the pictures are sufficiently large to be useful as contact prints.

There is a wide diversity among cameras of this type. One important difference is in the manner in which the bellows is extended. In some models it must be pulled out along a track on the bed of the camera. In other models, the camera front is supported by a lazy tongs arrangement (Fig. 40) which is extended either by hand or in some cases automatically. In most of the newer models, the lens front is brought into position automatically by a lever mechanism connected with the bed of the camera.

No provision is made for focusing on some of the cheaper cameras. Those models in which the front slides along a track on the bed of the camera are focused by means of a scale attached to the bed of the camera. Usually a pinion or a movable lever is added for convenience. Cameras in which the front is erected automatically are focused by unscrewing the front element of the lens or by a fitting which permits the lens and shutter to be moved back and forth on the front.

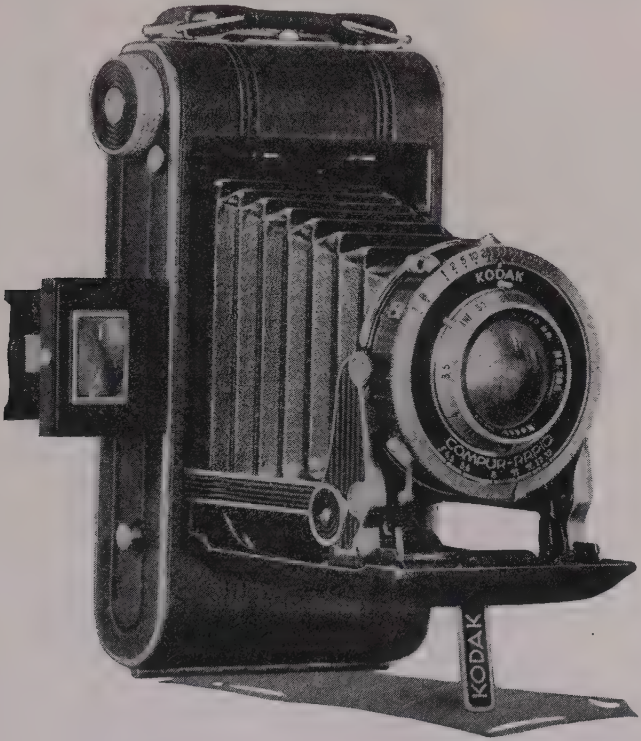

FIG. 39. Typical Hand Camera Using Roll Film. (Kodak)

The lenses fitted to cameras of this type range from single lenses on the less expensive models to the most advanced types of anastigmat on the more expensive. On cameras making pictures 2¼ × 3¼ or larger, the largest aperture of the lenses fitted is usually f:4.5 in the smaller models f:3.5 or in some even larger.

The camera is usually fitted with a reversible reflecting finder and in many cases with a direct vision finder in addition. Some have range finders and in a few cases the range finder is coupled to the focusing device in such a way that the lens is focused automatically as the distance of the object is determined.

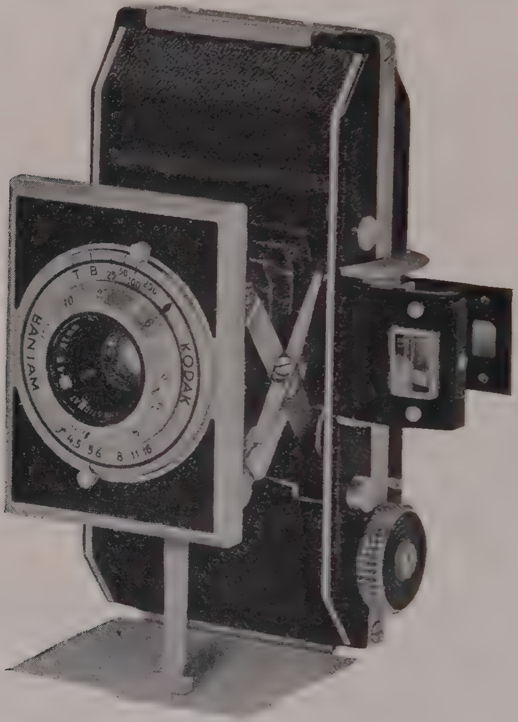

FIG. 40. Hand Camera with Automatically Extending Bellows. (Kodak-Bantam)

Hand Cameras Using Cut Film, Plates or Film Packs.—Hand cameras of this type appeal chiefly to the serious amateur as they are more suitable for difficult work than the more convenient roll film cameras. The ability to focus on the ground glass is of great importance in many phases of photography; furthermore, the possibility of using one of the many varieties of cut film, plates, or film pack appeals to the advanced amateur, since it enables him to select the sensitive material best suited to each particular subject. Usually, cameras of this type are fitted with a double extension bellows which enables them to be used for copying and in photographing small objects. A rising and also a sliding front movement are usually provided as well as a wire frame or direct vision finder. Some of the more expensive models are equipped with all of the movements common to the professional camera including reversing and swing back, front and side swing, wide angle bed, etc. Cameras of this type, being designed for serious work, are usually fitted with first quality anastigmat lenses and precision shutters with a wide range of speeds. Although designed primarily for use on a tripod, they may be used in the hand and focused by scale.

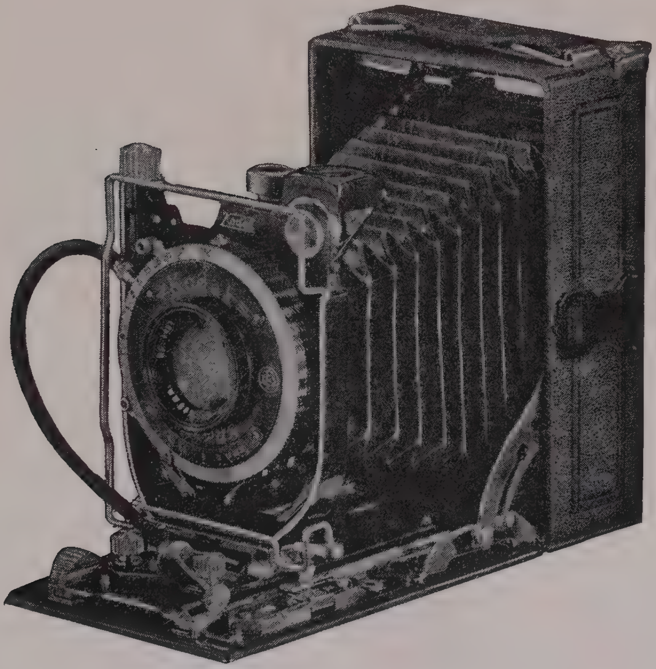

FIG. 41. Cut Film, Film Pack and Plate Camera with Ground Glass Focussing Back. (Recomar, Eastman Kodak Co.)

The Miniature Camera.—The last few years have witnessed a truly remarkable development of the small or miniature camera. The term miniature is loosely employed in present day photographic literature, but for the purposes of this discussion it will be assumed to mean a camera making pictures 4½ × 6 cm. (1⅝ × 2½ inches) or smaller.

The miniature camera owes its widespread popularity to the fact that (1) it is light and compact, easily carried and convenient in use, (2) the picture size being small and the focal length of the lens short, the depth of field is such that lenses of much larger relative aperture may be used than are feasible on larger cameras. Thus lenses with a relative aperture of f:2 or larger are fairly common on miniature cameras, whereas lenses with a relative aperture greater than f:3.5 are seldom useful on the larger cameras, owing to the limited depth of field. The large aperture lens enables pictures to be made in the home with ordinary lighting, street scenes at night, sporting events indoors, theatre photography by stage lighting and many other phases of photography which would be exceedingly difficult if not impossible with other types of apparatus. Being small and unobtrusive, the miniature camera is well suited to making pictures without attracting the attention of the subject: the so-called "candid photography."

Another very important factor in the popularity of the miniature camera is the vast amount of ingenuity which has been shown by the manufacturers in the design of instruments of this type and the skilled workmanship displayed in the better examples. The modern miniature camera is a precision instrument which despite its size is capable of producing results in most cases equal to and under many conditions superior to those of larger cameras.

Both scale focusing, twin-lens and reflex cameras are found in this class, but the first mentioned comprise by far the larger number. These may be divided into two classes: (1) those with a collapsible bellows and (2) those in which the necessary extension is secured by a metal tube with a sliding or helical-screw motion. A typical miniature camera is shown in Fig. 42.

Among the prominent features of cameras of this type are:

1. *Ready interchangeability of lenses.* Miniature cameras employing focal plane shutters are usually designed to permit the use of a number of lenses, thus enabling wide angle, high speed or telephoto lenses to be used as the occasion demands.

2. *Coupled range finder and focusing.* This enables the distance of the subject to be determined accurately and the lens adjusted for this distance in one operation.

3. *Direct optical view finder.* This frequently is designed to produce an enlarged image, and where the camera is designed for use with different lenses, either the area included is indicated in the field or the finder is designed to be adjustable both with respect to the size of the

image and the angle included so as to correspond with the different lenses for which the camera is designed. (See page 45.)

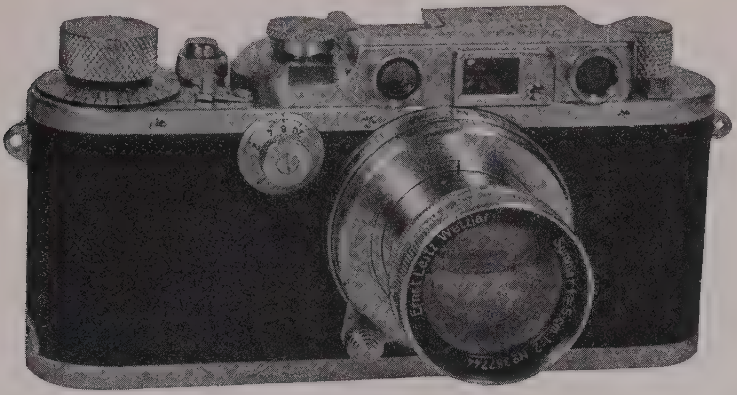

FIG. 42. Leica of E. Leitz, Wetzlar

4. *Focal plane or High Speed between-the-lens shutters.* With the former, most cameras have an interlocking device which results in a new section of film being wound into place when the shutter is being set. This automatically prevents double exposure since the exposure cannot be made until an unexposed section of film is in place. The focal plane shutters are designed to work very close to the sensitive material and consequently possess a very high efficiency. The maximum speed varies between 1/500 and 1/1000 of a second. On cameras using between-the-lens shutters, the Compur shutter is almost universal. The maximum speed of the extra-rapid Compur shutter used on many miniature cameras is 1/500 second.

5. *Film transport.* In most cases, the film spools are carried in light-tight metal magazines; the film being wound from the magazine for the exposure and wound back into the magazine when exposed. The magazine is placed in and removed from the camera in daylight. Daylight-loading roll film with the conventional paper packing is used only in those cameras making pictures 4½ × 6 cm (1⅝ × 2½ inches) or half this size, namely 3 × 4 or 4 × 4 cm. In cameras using a perforated 35 mm. film, the winding key operates a sprocket which engages the perforations along the side of the film. An automatic stop locks the winding key when the amount of film required for the next picture is in place thus preventing overlapping exposures.

6. *Attachments for specialized work.* One of the very important reasons for the present popularity of the miniature camera is due to the attention which the manufacturers of some of the more popular models have given to the designing of attachments for specialized work. In some cases, there are several hundred such attachments designed for such diverse fields as copying, photomicrography, stereoscopy, and macrophotography, aside from special features such as a film rewind for making a number of exposures in rapid succession, synchronizing photoflash bulbs, self-timers, devices for panoramic photography as well as a full line of equipment for processing miniature camera negatives and printing both by contact and projection. These have made some models of the miniature camera more nearly a universal camera than any other now available.

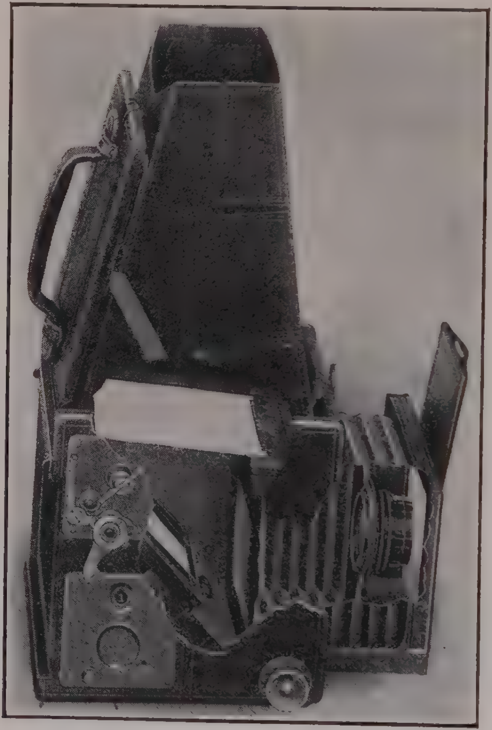

Fig. 43. Principle of the Reflex Camera

The Reflex Camera.—The reflex camera is so called from its construction (Fig. 43). A mirror placed at an angle between the lens and the sensitive film reflects the image to a focusing screen at the top of the camera where it is seen right side up and in full size up to the moment of exposure. When the exposure lever is depressed the mirror swings up out of the way and covers the focusing screen. Upon reaching this position, it releases the focal plane shutter exposing the film or plate. The exposure is governed by the width of the aperture and the rate at which it moves across the surface of the sensitive material. In some reflex cameras, the mirror returns automatically to its original position as soon as the exposure lever is released; in others, an interlocking device makes it necessary to return the mirror to its original position in front of the film before the shutter can be rewound for a second exposure. This prevents accidental exposure.

Reflex cameras are available in a wide variety of models. The smaller are usually designed for use with roll film; however, in the larger sizes it is usually possible to use cut film of plates, either in holders or a changing box (magazine), film packs in an adapter; or roll film in a detachable roll film holder.

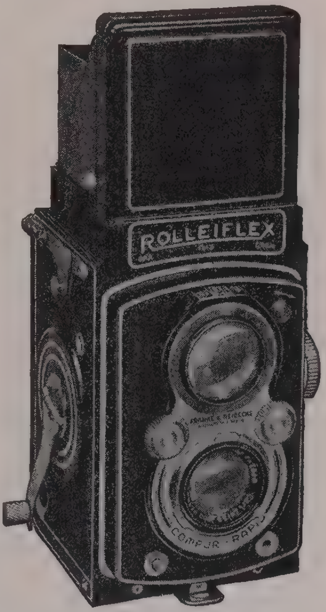

FIG. 44. Twin Lens Camera (Rolleiflex)

The reflex camera is favored by those who wish to be able to see the image on the focusing screen so as to study the arrangement of the subject to better advantage, but object to the inconvenience of the stand camera. Also it is one of the best types of cameras for photographing rapidly moving objects since the focusing arrangement enables the moving object to be kept properly placed in the picture and in sharp focus while the focal plane shutter makes possible the rapid shutter speeds required to stop motion.

The Twin Lens Camera.—This type of camera, shown in detail in Fig. 44, consists essentially of two cameras with matched lenses, one of which is used for focusing and arranging the subject and the other for making the picture. Cameras of this type are made in sizes

2¼ × 2¼ and smaller; above this size the camera becomes rather bulky. The twin lens camera allows the image to be followed on the focusing screen to and during the exposure. There is no delay in exposure, as in the reflex, where time must be allowed for the swinging mirror. On the other hand, the images on the focusing screen and the film do not coincide exactly because of the separation of the two lenses. This is known as the parallax error and is unimportant in practice except in nearby subjects. Certain cameras of this type are fitted with devices which compensate for the parallax differences by masking the finder image.

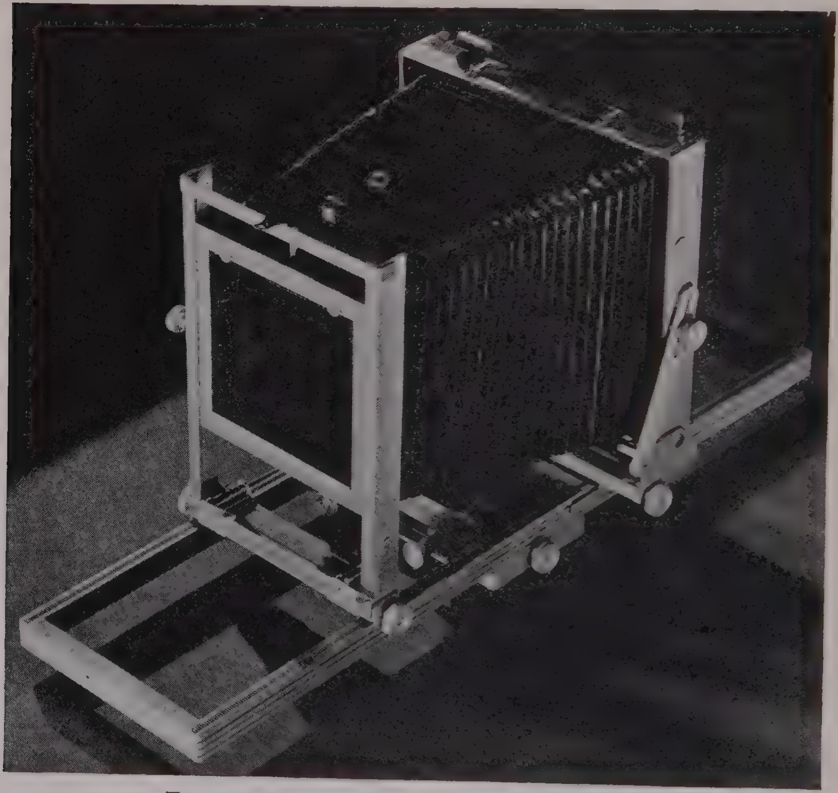

FIG. 45. All Metal View Camera. (Eastman)

The twin lens camera does not offer the same facility as regards interchangeability of lenses as other cameras, since in this case, it is obvious that not one but two lenses are required. Aside from the expense involved, it is difficult to provide for the proper separation between lenses of different sizes on the camera front. Thus, if space is allowed for the larger telephoto lenses, the distance is too great for the best results with the smaller lenses.

The twin lens camera in its modern form is deservedly popular on account of its simplicity, the ability to focus the image as in the reflex camera, and its ruggedness and general dependability.

Professional Cameras.—The so-called *view* camera (Fig. 45) is intended primarily for general exterior and interior photography. It is designed for use with cut films or plates and is made as light and portable as is consistent with strength and rigidity. Usually it has a long bellows extension, may be focused from either the front or the rear, and the movements include a rising front, side and vertical swings to the back, and reversing back. It is not fitted with either a finder or a focusing scale.

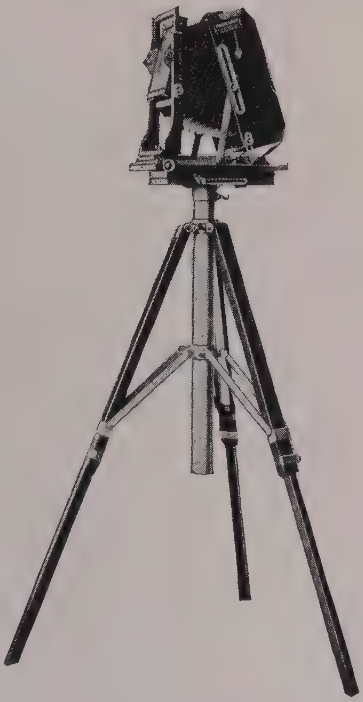

Fig. 46. Typical Commercial Camera. (Century Universal)

The *commercial* or technical camera (Fig. 46) has a much wider range of movements so as to meet the most exacting demands of technical photography. The vertical and horizontal swings have a much wider range than in the view camera and the front likewise is fitted with similar swings thus simplifying the photographing of tall buildings, cramped interiors, and commercial or industrial products requiring unusual perspective.

The *commercial studio* camera (Fig. 47) is similar except that it is heavier and more substantially constructed since weight is not as important as in a camera intended for use outside the studio. A rigid stand enables the camera to be raised to a height of from 8 to 9 feet from the floor and inclined to any desired angle.

Cameras of nearly all types are used as occasion demands for press photography but the camera usually associated with press photography is a rigidly constructed hand camera using cut film, plates, or film pack, and fitted with a focal plane as well as a between-the-lens shutter. To the latter is attached a synchronizing device for simultaneous operation

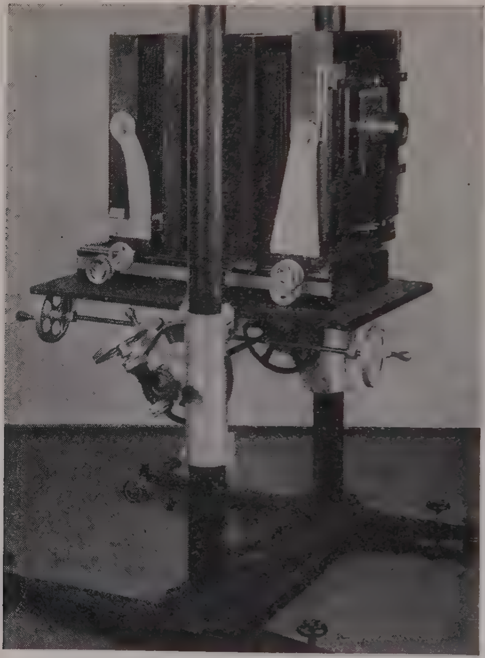

FIG. 47. Modern Commercial Studio Camera Stand (Deardorff)

of a photoflash bulb and the shutter. At the present time, these devices are all separate attachments as no camera with a built-in synchronizer for photoflash lamps has been introduced commercially. Focusing is usually by a scale except when conditions permit the use of the ground glass focusing panel at the rear of the camera. Cameras in which a range-finder is coupled to the lens so that the latter is automatically focused when measuring the distance of the subject are a recent introduction. A wire frame or a direct vision optical finder enables moving objects to be located readily with the camera held at eye level.

Cameras designed for professional *studio portraiture* (Fig. 49) have a long bellows and are substantially built, particularly in the front, so as to accommodate the long-focus, large aperture lenses desired in portrait work. Cameras of this type are focused from the rear, and the back is provided with vertical and horizontal movements. A sliding carriage enables two pictures to be made on one film or plate. In some cases, this sliding carriage is so designed that the loaded film or plate holder may be placed in one side and the slide withdrawn before the image is focused. Then when the subject is arranged and the image focused, the shutter is closed and the carriage shifted to place the film or plate in position for the exposure. This greately reduces the time elapsing between focusing and the exposure and is of real assistance in securing more lifelike portraits.

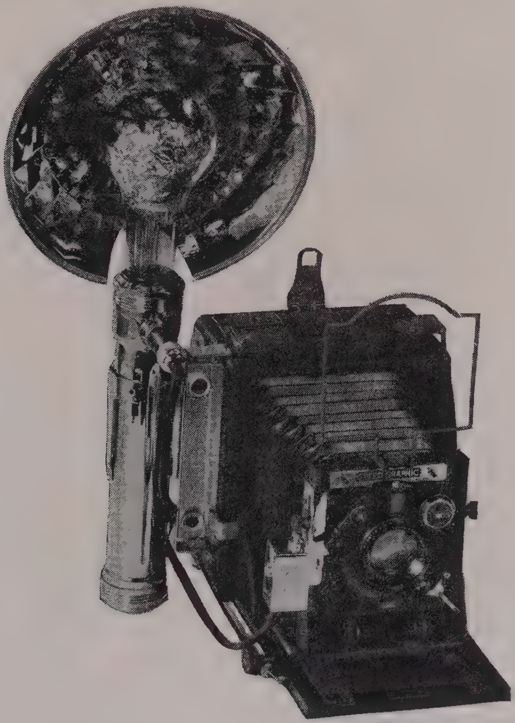

FIG. 48. Press Camera with Synchronizer for Photoflash Bulbs. (Speed Graphic Camera. Mendelsohn Speed-Gun Synchronizer)

An integral part of the outfit for studio portraiture is a strongly constructed stand which enables the camera to be raised from a position a few inches above the floor to an elevation of about five feet and provides means for inclining the camera at an angle.

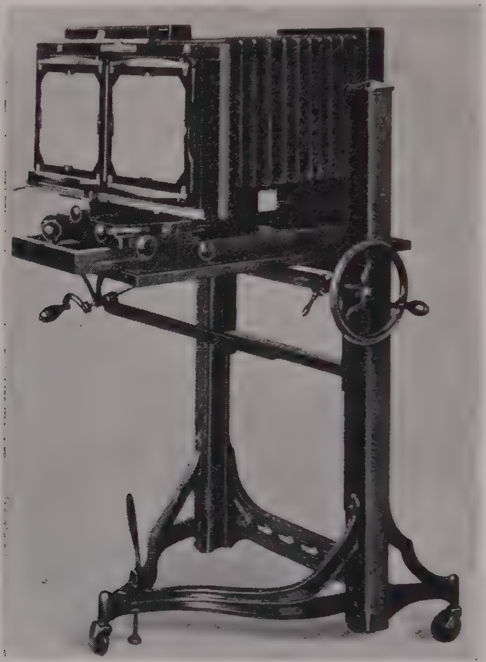

FIG. 49. Century Studio Camera and Stand

Two studio cameras of the reflex type are available commercially but are not in widespread use. One of these is arranged so that the image is seen from the side; in the other a double mirror enables the image to be seen from behind the camera.

A number of portrait photographers use reflex cameras when making pictures of children.

CHAPTER III

PHOTOGRAPHIC OPTICS

Introduction.—Light is that form of energy which is capable of affecting our sense of sight. The exact nature of light has been a subject of much conjecture among physicists and philosophers for many centuries. The ancients considered that a beam of light consisted of a stream of microscopic particles which radiated uniformly in all directions from the light source. This corpuscular theory of light held full sway in the minds of most physicists until Thomas Young, in the year 1800, published a paper in the Philosophical Transactions of the Royal Society entitled, "Outline of Experiments and Inquiries Respecting Light and Sound." In this and subsequent papers, Young showed both by experimentation and mathematical reasoning that light energy must be of an undulatory or wave nature if such phenomena as diffraction and interference are to be explained in a rational manner. The work of such scientists as Foucault in measuring the velocity of light in different media, Fraunhofer in establishing the wave length of various dark lines in the solar spectrum, and Maxwell in developing the electro-magnetic theory of light and its experimental verification, gave the impression that the corpuscular theory of light was dead. Such was not the case, however. In the latter part of the nineteenth century, it became necessary to attempt the explanation of a newly-discovered phenomenon—namely, the photoelectric effect. Considerable difficulty was encountered in explaining this effect by using the basic concept of light as being wholly of an undulatory character. In fact, it seemed necessary to again regard light as corpuscular in nature. This time the corpuscles became known as quanta and associated with each quantum was a characteristic frequency. Hence light is now regarded as being comprised of bundles of energy in the form of quanta, which have definite wave properties. Hence, light is considered as possessing undulatory as well as corpuscular characteristics. Perhaps the nature of light may be best expressed as being undulatory and/or corpuscular, the selection depending entirely upon the physical phenomenon which is to be explained. The wave theory is usually employed when explaining such phenomena as reflection, refraction, interference, polarization; and the quantum theory for such phenomena as photoelectricity, and recent effects in the field of X-rays and radiation.

Velocity of Light.—In 1675, the Danish astronomer Romer observed that the time of revolution of the satellite of Jupiter varied with the position of the earth in its orbit. By studying and recording the magnitude of this variation, Romer was able to give the velocity of light in free space as 3.0×10^{10} centimeters per second, a figure in remarkably close agreement with the 2.99796×10^{10} centimeters per second, given by Michelson as a result of a series of laboratory experiments published in 1926. As a result of Michelson's work, the velocity of light is probably more accurately known than almost any other physical constant. The velocity of light in other media depends upon the nature of the medium and the frequency of the light.

Reflection and Refraction of Light.—A ray of light traveling in a homogeneous medium forms a straight-line path. However, when a light ray is incident upon a surface separating two different media, the path is in general broken at that point. In fact, the ray is divided into two portions, one of which proceeds into the second medium in a different direction, while the other is reflected back into the first medium.

Should a normal be erected to the boundary surface at the point where it receives the incident ray, the angles which the incident, refracted and reflected rays make with this normal, all lie in the same plane. Further *the incident and reflected rays make equal angles with the normal.* See Fig. 50. The angle of the refracted ray with the normal, however, is smaller than either the incident or reflected angle, provided the second medium is more dense than the first.

The Law of Reflection.—The angle of incidence is equal to the angle of reflection and both lie in the same plane.

The Law of Refraction.—The sine of the angle of incidence divided by the sine of the angle of refraction equals the index of refraction of the second media with respect to the first. In mathematical language, this may be expressed as:

$$n = \frac{\text{sine of the angle of incidence}}{\text{sine of the angle of refraction}} = \frac{\sin i}{\sin r}$$

where n is known as the index of refraction of the second media with respect to the first.

In terms of the velocity of light, the index of refraction of any particular substance may be expressed as the ratio between the velocity of light in vacuum to that of the velocity of light in the medium being considered. Therefore, $n = V/V'$ where V represents the velocity of light in vacuum and V' the velocity of light in the medium being considered. The refractive indices of several common optical materials are given in the following table.

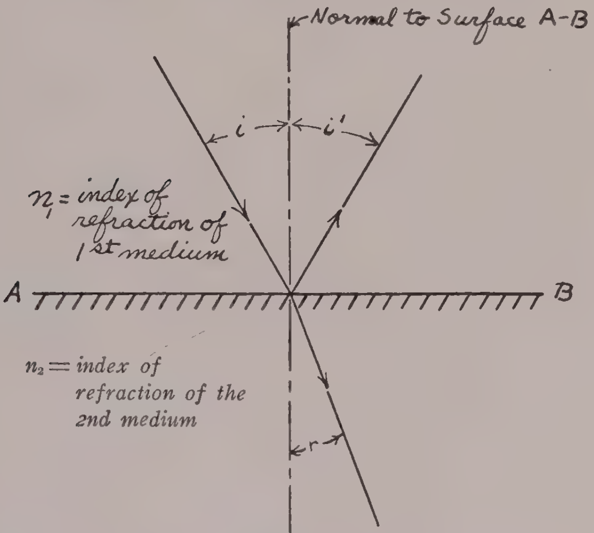
Normal to Surface A-B
i
i'
n_1 = index of refraction of 1st medium
A
B
n_2 = index of refraction of the 2nd medium
r

FIG. 50

i = angle which incident ray makes with normal to surface A–B
i' = angle which reflected ray makes with the normal to surface A–B
r = angle which refracted ray makes with the normal to surface A–B

INDEX OF REFRACTION OF OPTICAL GLASS
(relative to air)

Type of Glass	Wave length, millimicrons						
	400	450	500	550	600	650	700
Silicate Flint	1.6528	1.6391	1.6302	1.6240	1.6193	1.6157	1.6129
Telescope Flint	1.5393	1.5320	1.5270	1.5233	1.5206	1.5184	1.5166
" Crown	1.5406	1.5346	1.5304	1.5273	1.5249	1.5231	1.5216
Borate Flint	1.5938	1.5858	1.5802	1.5761	1.5730	1.5705	1.5685
Dense Crown	1.5917	1.5855	1.5812	1.5780	1.5755	1.5736	1.5720
Light Crown	1.5232	1.5174	1.5134	1.5104	1.5082	1.5064	1.5049
Quartz	1.5577	1.5519	1.5488	1.5460	1.5438	1.5421	1.5407
Fused Quartz	1.4700	1.4656	1.4624	1.4600	1.4581	1.4566	1.4553

The relative intensity of the reflected and refracted rays depends upon the character of the boundary surface between the two media. In general, a polished metallic surface reflects the larger proportion of light. The refracted portion is absorbed in an exponential fashion as it proceeds into the second medium.

Wave Character of Light.—Fig. 51 represents the simplest form of wave motion, namely a sinusoidal motion of particles forming a transverse wave. This diagram is introduced primarily to aid in the definition of terms which are commonly used when describing wave phenomena. The distance between corresponding positions of two adjacent waves represents one *wave length,* the symbol for which is λ. Let V be the velocity of travel of the wave and T the time required for one wave to pass a fixed point. Then $\lambda = VT$. The quantity T is usually referred to as the period, while its reciprocal, $1/T$, is known as the frequency, the symbol for which is f. Expressing λ as a function of f, we have $\lambda(T/f)$.

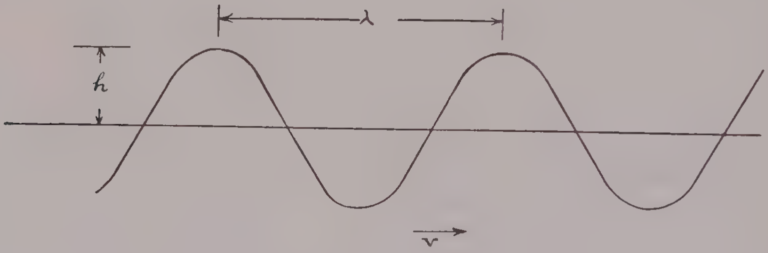

FIG. 51

$\lambda =$ One wave-length mμ
$V =$ Velocity of travel of the wave, cm./sec.
$h =$ Amplitude of the wave, mμ
$T =$ period, or the time required for one wave to pass a fixed point, sec. $(T = \lambda/V)$
$f =$ frequency $= 1/T = V/\lambda$

The wave length of light waves is too short to be conveniently expressible in the customary units of length such as inches or centimeters. The two units ordinarily used are the millimicron and the Angstrom; the former is 1/1,000,000 part of a centimeter while the latter 1/10,000,000 part of a centimeter. Visible light falls within the wave length range from 400 to 700 millimicrons. Within this region are found the following color sensations, the corresponding wave lengths being given below:

Violet	350 to 450 mμ
Indigo	450 to 460 mμ
Blue	460 to 500 mμ
Green	500 to 580 mμ
Yellow	580 to 590 mμ
Orange	590 to 620 mμ
Red	620 to 750 mμ

Another important concept to understand in connection with the wave theory of light is the so called "*wave front.*" The motion of a light wave in three-dimensional space may be likened unto the motion of a surface in which the phase of disturbance is everywhere identical. A surface of this character represents a so-called wave front. To illustrate this further, let us consider *S*, Fig. 52, as a point source of light located in a homogeneous medium. Under such conditions, the velocity of propagation will be equal at all points and in all directions, and the wave front will emanate from the source as spheres of ever-increasing radii. At any particular instant, the disturbance may be visualized as a series of concentric spheres the loci of which are the source of light.

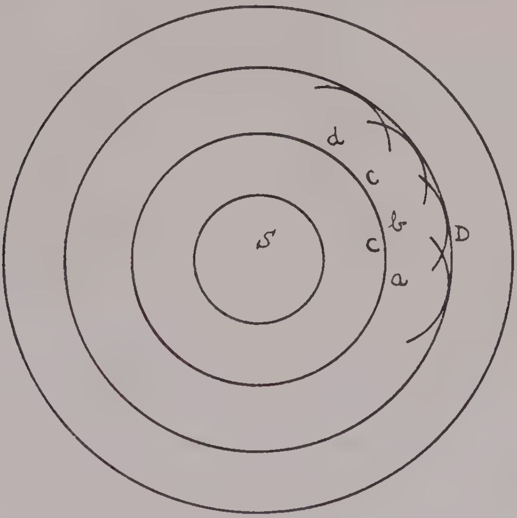

Fig. 52

About the middle of the seventeenth century, Huygens pointed out that successive wave fronts need not of necessity be considered as having originated from the light source. In other words, the wave front may be considered as having originated from the disturbance on wave front C instead of from the source S, in which case each point on the wave front C would act as a center of disturbance from which secondary spherical waves emanate. Therefore, the wave front D describes the envelope of spheres of equal radii whose centers lie on surface C. Huygens' wave front method offers a most direct approach to the facts of image formation and is consequently an invaluable aid of geometrical optics.

Polarized Light.—When one oscillates the end of a stretched rope with a periodic up-and-down motion, a set of transverse waves pass along the rope. A wave train of this type is known as a *plane-polarized* train of waves. If instead of moving the hand up and down a circular motion is imparted to it, a set of *circularly-polarized* waves are sent out along the rope. And likewise, if an elliptical motion is given to the hand, the waves which travel along the rope are said to be *elliptically-polarized.* Ordinary or natural light is considered to be composed of beams of plane-polarized light where all azimuths are represented.

It is possible by various polarizing devices to change a natural light wave in such a fashion that only one direction of vibration is left, that is, it becomes plane-polarized. Natural light passing through a crystal of Iceland spar becomes plane-polarized. Ordinary unpolarized light which is specularly reflected at an angle of 32 to 37 degrees from any non-metallic surface is strongly polarized by the act of reflection. Light from a clear blue sky arising at right angles to the sun's rays is also strongly polarized.

Absorption.—When light passes through a material, some of its energy is lost by surface reflection and some by absorption within the material itself. Fig. 53 shows a beam of intensity I_0, incident upon the surface AA of a piece of glass of thickness x. At the first surface approximately 4 per cent of the incident light is lost by reflection in beam Ir_1. Of the remaining 96 per cent a certain amount is lost by absorption (beam Ia), the magnitude of this loss depending upon the character of the glass as well as its thickness. At the second surface (BB) another reflection loss occurs so that the final beam Ix has an intensity equal to $I_o - (I_{r_1} + I_a + I_{r_2})$. Therefore, the fraction of the incident light which is actually transmittal is represented by I_x/I_o—this quantity being known as the transparency of the material. The reciprocal of the transparency is known as the *opacity,* that is

$O = 1/T$. The so-called *density* of the material is defined as the natural logarithm of the opacity:

$$D = \log_{10} O = \log_{10} \frac{1}{T}.$$

In general, the absorption of a material depends upon its thickness in an exponential fashion in accordance with Bouguer's law, which may be stated as follows: $I = I_o t^x$ where x is the thickness of the material and t the transmission for a unit thickness. This law may also be written $I = I_o e^{ax}$ where a is the so-called absorption coefficient of the material.

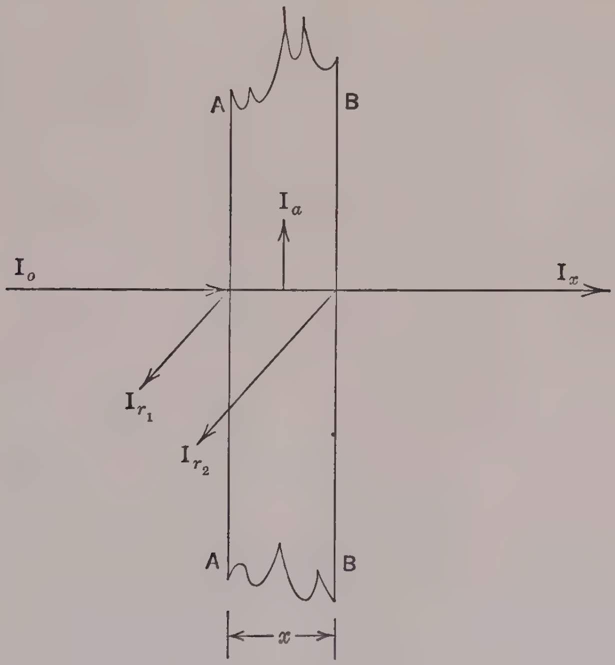

FIG. 53. Principles of Refraction and Reflection

The amount of light which a material absorbs is also a function of the wave length of the light. Therefore, absorption is said to be a selective phenomenon. Materials which are non-selective are of a neutral gray color.

The Reflection of Light by a Spherical Surface.—Fig. 54 shows a concave spherical reflection surface whose center is at V. The line

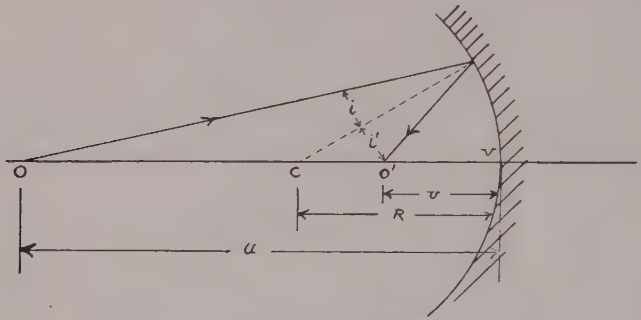

FIG. 54. Reflection by a Spherical Mirror

OV is termed the axis of the mirror and the point V its vertex. The location of the image O' of the axial point object O may be determined in accordance with the following formula:

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f},$$

where u equals the object distance OV, v the image distance $O'V$, and f the focal length of the mirror whose value equals $R/2$.[1]

If one wishes to image a light source at infinity, that is, to produce parallel light by means of a concave mirror, it becomes necessary to place the light source at the focus of the mirror. Under these conditions, all the rays which fall upon the mirror will be reflected parallel to the axis. It becomes obvious that it is advantageous to make the mirror as large as possible in order to receive a high percentage of the rays from the source and hence concentrate more light upon distant objects. The previous formula is only a good first approximation and it will be found by experimentation that as the mirror is made larger the imagery becomes more and more inaccurate and parallelism of the projected rays less perfect. If instead of using a spherical mirror, a parabolic shape is resorted to and the source placed at its focus, it will be found that better results are obtained, since the geometrical properties of a parabolic surface are such that all rays are projected in a parallel beam no matter how large a portion of the surface is utilized. Fig. 55 shows an exaggerated example of the difference in action of the spherical and parabolic reflectors.

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[1] In order to avoid ambiguity, it becomes necessary to adopt a sign convention to insure consistency in the uses of formulae relating to optical imagery. Since no convention is strictly universal, we shall select that used by Messrs. Hardy and Perrin in their recent text entitled "Principles of Optics." To quote:

"1. Draw all figures with the light incident on the reflecting or refracting surface from the left.

"2. Consider the object distance u positive when the object lies at the left of the vertex V.

"3. Consider the image distance v positive when the image lies at the right of the vertex V.

"4. Consider the radius of curvature R positive when the center of curvature lies at the right of the vertex.

"5. Consider slope angles positive when the axis must be rotated counterclockwise through less than $\pi/2$ to bring it into coincidence with the ray.

"6. Consider angles of incidence and refraction positive when the radius of curvature must be rotated counterclockwise through less than $\pi/2$ to bring it into coincidence with the ray.

"7. Consider distances normal to the axis positive when measured upward."

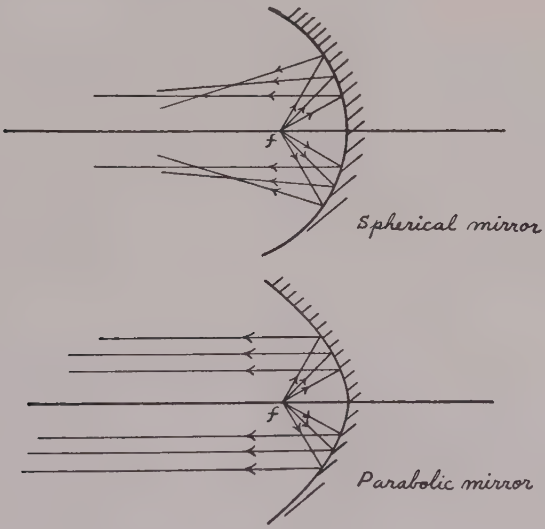


FIG. 55. Exaggerated Example of the Difference in Projection by a Spherical and Parabolic Mirror

The Refraction of Light from a Spherical Surface.—In Fig. 56 a spherical refracting surface is shown of which center is at *C* and vertex at *V*. A point object *O* lies in a medium of refractive index n_1. Its image *O′* is formed in the second medium having an index of refraction n_2, the boundary surface between the two media being spherical. Let OO' represent the axis of this system and the point V the vertex of the refracting surface. Θ and Θ' are the so-called slope angles of the rays OI and IO'. The law governing the formation of image O' from object O in this case may be stated as

$$\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$$

where u is the object distance, V the image distance, n_1 and n_2 the indices of refraction of the first and second media respectively, and R the radius of the spherical boundary surface between these two media.

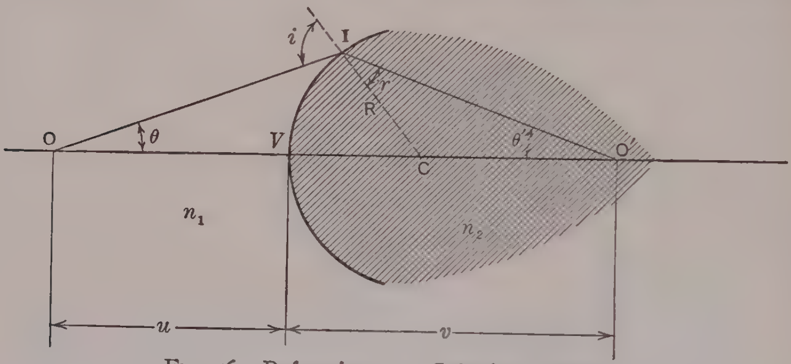


FIG. 56. Refraction at a Spherical Surface

The Thin Lens in Air.—Fig. 57 represents a thin lens bounded by two spherical surfaces having vertices at V_1 and V_2. The image of an axial point object O is represented by O'. Let OV_1 and V_2O' equal u and v, respectively. Since it is assumed that this lens is to be used in air, n_1 and n_3 will equal unity. For the sake of convenience, let $n_2 = n$, the index of refraction of the lens material. Under these conditions, the law governing the formation of image O' may be stated

$$\frac{1}{u} + \frac{1}{v} = (n - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right].$$

The derivation of this equation, as given in any reliable text on geometrical optics, is made on the assumption that t, the thickness of the lens, is zero. Since this is an obvious impossibility, this equation must be regarded as an approximation to be used only in those cases where the actual thickness of the lens is a small percentage of its focal length. A later section (see page 82) offers a more extensive analysis for use in those cases where the lens thickness itself is of sufficient size to be important.

Figure 58 shows the various types of spherical thin lenses encountered in practice. Those shown on the top row of this figure are so-called converging lenses, since a pencil of light falling upon one of these is made more convergent. A converging lens, frequently called a positive lens, is characterized by the fact that it is thicker at the center than at the edges and therefore has a positive focal length. Diverging or negative lenses, on the other hand, are always thinner at the center than at the edge. A pencil of light incident upon a diverging lens is rendered more diverging, thereby producing a virtual image. Fig. 59

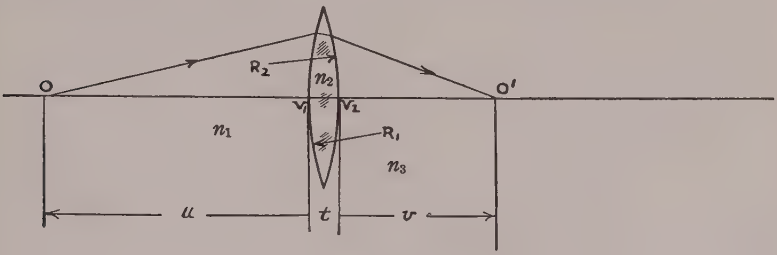


Fig. 57. Imagry by a Thin Lens

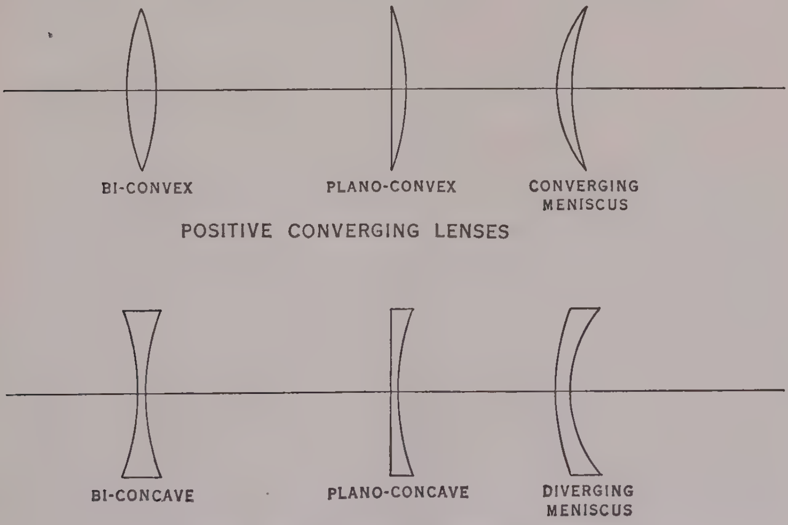


Fig. 58

shows the action of both a converging and a diverging lens upon a parallel beam of light. It will be noted that the converging lens forms a real image at a distance f from the lens and on the opposite side from the source. The diverging lens, on the other hand, forms a virtual image at a distance f from the lens but on the same side as the source.

Magnification Produced by a Thin Lens.—So far, only the images of points lying on the optical axis of the lens have been considered. Fig. 60 shows an object h (represented by an arrow), located at a distance u from the lens. The image of this object may be located by tracing two rays from the top of the arrow, the one ray OA being parallel to the optical axis, while the other, OC, is directed toward the optical center of the lens. At point A, the ray OA will be refracted through the focal point f and will therefore continue in the image space in the direction If. The ray OC, however, will pro-

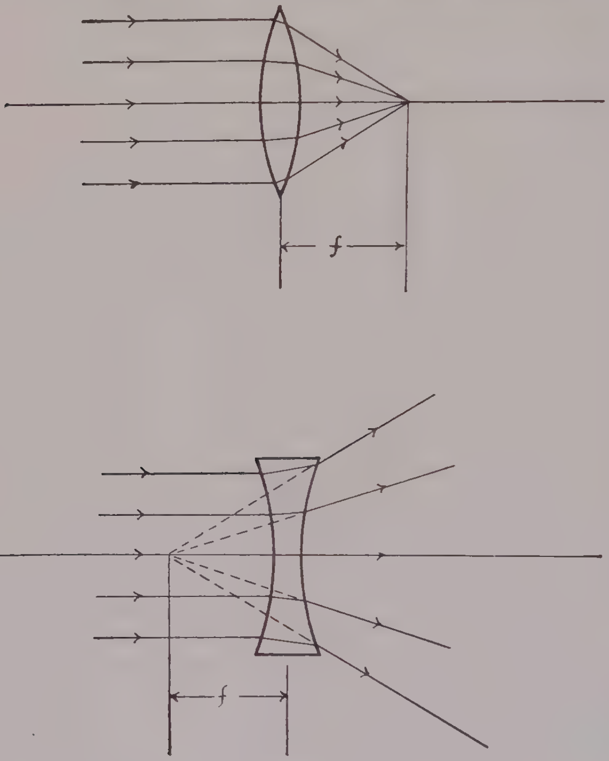


FIG. 59

ceed unrefracted in the direction CO', where OCO' is a straight line. Since the rays IO' and CO' intersect at point O' this may be regarded as the image of point O. The image h' is an inversion of the object h, and, in general, it will differ in size from the object.

If h and h' represent the height of object and image respectively, the magnification produced by the thin lens may be said to equal h'/h. It will be observed from the geometry of Fig. 60 that the magnification produced by the thin lens is also equal to v/u. Fig. 61a indicates the relation between object and image for a positive converging lens when the object is located within the focal length of the lens. Here the image is much enlarged, erect, and on the same side of the lens as the object, that is, a *virtual* image. Such is the action produced by a simple magnifying lens or reading glass.

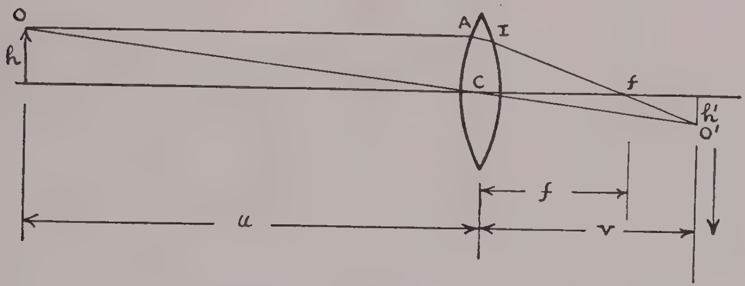


FIG. 60. Magnification Produced by a Thin Positive Lens

Figure 61b shows the image formed by a diverging lens. In the case shown, the image is virtual, erect, and smaller than the object. Therefore, a diverging lens makes objects look smaller. It has the compensating advantage, however, that the field of view has been considerably enlarged.

The Diopter.—The dioptric power of a lens is equal to the reciprocal of its focal length in meters, that is, $D = 1/f$. Therefore, a lens whose focal length is one meter has a strength of one diopter. Likewise, a lens whose focal length is one-half meter has a power of two diopters, etc.

Systems of Thin Lenses.—The final image produced by a system of thin coaxial lenses is found by using the image produced by the first lens as the object of the second lens, etc. throughout the system. A somewhat simpler and more direct method is to compute the focal length of the combination of thin lenses and treat the combination as a single lens. This may be obtained by dividing the continued product of the focal length of each of the lenses in the system by the sum of their focal lengths provided the lenses are in intimate axial contact. When

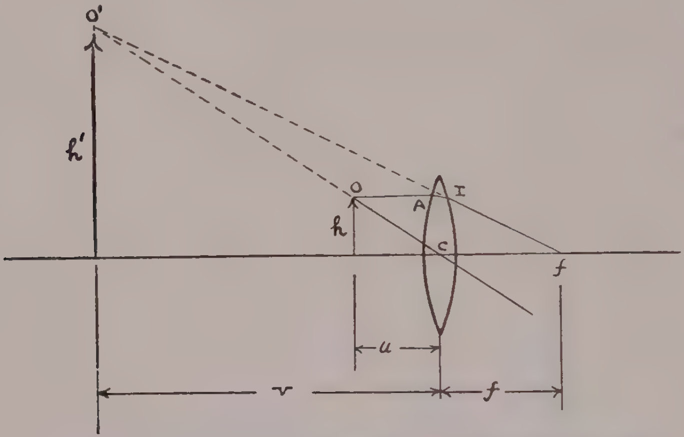


FIG. 61a. Magnification Produced by a Thin Positive Lens

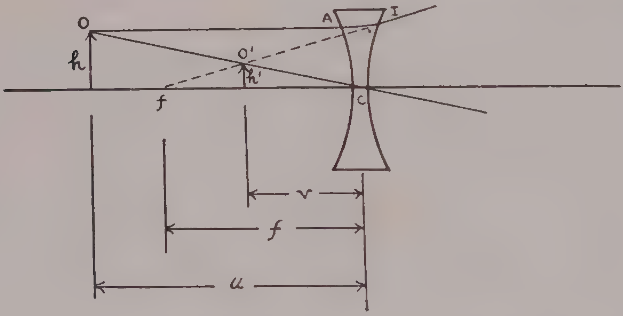


FIG. 61b. Magnification Produced by a Negative Lens

large gaps exist between the individual lens elements, the former method outlined above must of necessity be used.

The Thick Lens in Air.—For those cases where the thickness of the lens is a substantial portion of the focal length, the approximate formulae given in the preceding sections are inadequate. When this is the case, the formula

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

may be used, provided u and v are measured from the two *principal points* of the thick lens, and if for f we use the "*equivalent focal length.*" Point P_1 and P_2 in Fig. 62 are the two principal points for the biconvex lens shown. The equivalent focal length in this case is the distance E.F.L. It will be noted from examining Fig. 62 that u and v are measured from the two principal points.

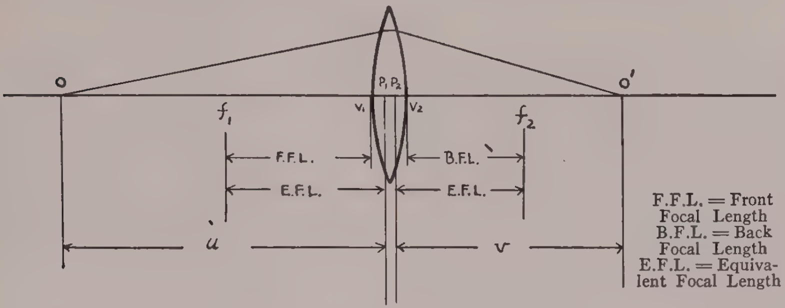

O
P₁ P₂
O'
f₁
V₁
V₂
f₂
F.F.L.
B.F.L.
E.F.L.
E.F.L.
u
v
F.F.L. = Front Focal Length
B.F.L. = Back Focal Length
E.F.L. = Equivalent Focal Length

FIG. 62. The Thick Lens in Air

The principal points of any lens lie on the axis and are conjugate one to another, that is, one point is the image of the other. Hence, an entrance beam which passes through the first principal point converges from the second principal point and is parallel to the entrance beam. The location of the two principal points and the equivalent focal length of a thick lens may be computed according to the equations given below:

$$V_1P_1 = \frac{tR_1}{n(R_1 - R_2) - t(n - 1)},$$

$$V_2P_2 = \frac{tR_2}{n(R_1 - R_2) - t(n - 1)},$$

$$\text{E.F.L.} = \frac{nR_1R_2}{(n - 1)[n(R_2 - R_1) + t(n - 1)]}.$$

The quantity t represents the thickness of the lens, n the index of refraction of the glass, and R_1 and R_2 the radii of the front and rear lens surfaces.

A biconvex or biconcave lens with surfaces of equal curvature have the two principal points located at equal distance from the two vertices. When one surface is more strongly curved than the other, both principal points tend to move toward the more strongly curved surface. When one surface of the lens is plane, one principal point lies at the vertex of the curved surface. The principal points for a meniscus lens usually lie entirely outside of the lens.

From Fig. 62, it will be observed that a thick lens has three focal lengths: the *back focal length,* the *front focal length,* and the *equivalent focal length.* The equivalent focal length represents the focal length of a thin lens which would have the same strength as that of the thick lens being computed. It will be observed that the back focal length and the front focal length are measured from the lens surfaces instead of from the principal point.

Planes erected through the principal points of a lens orthogonally to the lens axis are known as principal planes, or planes of unit magnification. Fig. 63 indicates a method of locating an image formed by a thick lens. Here the planes P_1 and P_2 are the principal planes of the lens. With O as the object, the ray OP_1 will emerge at P_2, the ray P_2O' being parallel to OP_1. Likewise, the ray OA, which is parallel to the axis, will emerge at A', passing through the focus f and continuing to the image point O'. The intersection of ray P_2O' and $A'O'$ locates the position of image O'. Here again, the ratio between h' and h is the magnification produced by the lens.

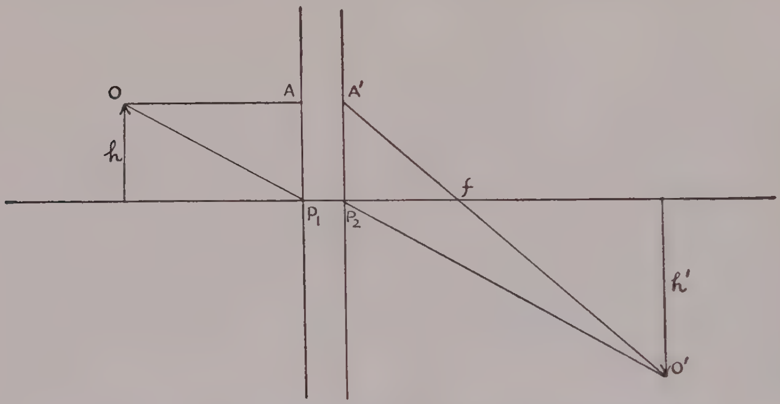


FIG. 63. Method of Locating an Image by Principal Planes

Combination of Thick Lenses.—When two thin lenses of focal length f_1 and f_2 are placed in contact, the focal length of the combination is given by

$$F = \frac{f_1 f_2}{f_1 + f_2} .$$

When thick lenses are used, however (or thin lenses which are not in contact), the effective focal length of the lens system is given by the following equations:

$$F = \frac{f_1 f_2}{f_1 + f_2 - a}.$$

Here f_1 and f_2 are the equivalent focal lengths of the two thick lenses and a is the distance from the second principal point of the first lens to the first principal point of the second lens.

The action of two thin lenses may be considered equivalent to a single thick lens having equivalent focal lengths as given by the foregoing equation and two principal points as located by the two following equations:

$$p_1P_1 = \frac{af_1}{f_1 + f_2 - a},$$

$$p_2P_2 = \frac{af_2}{f_1 + f_2 - a}.$$

In the foregoing equations, p_1P_1 represents the distance from the first principal point of the first single thick lens to the principal point of the equivalent thick lens; and the distance p_2P_2 that from the second principal point of the second component lens to the second principal point of the equivalent lens.

Entrance and Exit Pupils.—Let us consider the action of two thin lenses between which is placed a diaphragm or stop. Such a system is shown in Fig. 64. This is representative, in an elementary sort of way, of the construction of a typical photographic objective.

When an objective of this type is examined from the object side, the size of the diaphragm appears to be that of E' rather than E, where E' is the image of E as formed by the front lens. Likewise, when E is examined visually from the rear of the objective, it appears to be of size E'' instead of E, where in this case E'' is the image of E as formed by the second lens. According to the nomenclature developed by Abbe, E itself is known as the aperture stop while E' is called the *entrance pupil* and E'' the *exit pupil.*

Although the entrance and exit pupils in Fig. 64 are larger than the actual aperture stop, such need not necessarily be the case. In any well-designed photographic objective, however, the aperture stop is usually smaller than either the entrance or exit pupil, that is, it is smaller than the images of this aperture stop as formed by the front and rear lens elements respectively. It should be noted that the entrance and exit pupils E' and E'' may be found directly by using E as an object and determining its image as formed by the first and second lenses respectively.

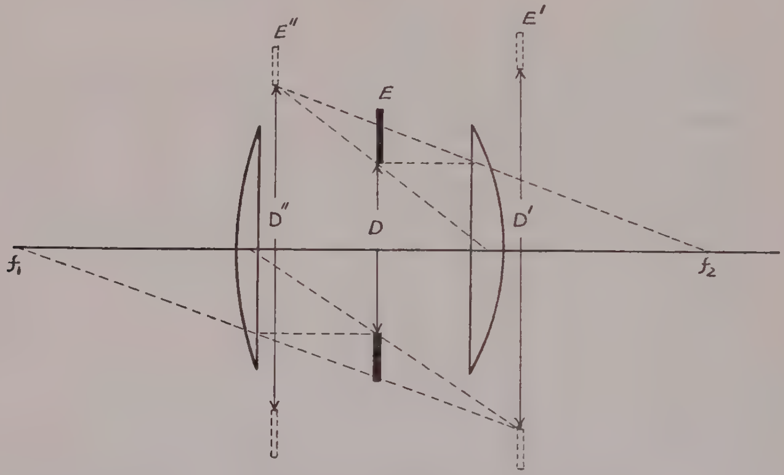


FIG. 64. Imagry of Entrance and Exit Pupil

D = actual diameter of diaphragm
D' = diameter of the "entrance pupil"
D'' = diameter of the "exit pupil"

Relative Aperture.—The speed or light-gathering power of a photographic objective is usually spoken of in terms of the so-called *relative aperture.* Relative aperture is arbitrarily defined as the ratio between the focal length of the lens and the diameter of its entrance pupil.

$$\text{R.A.} = \frac{f}{D'}$$

where R.A. = relative aperture or f/number,
f = focal length,
D' = diameter of the entrance pupil.

Therefore, if a lens has a focal length of 100 millimeters and the diameter of the entrance pupil is 20 millimeters, its relative aperture, or speed, is equal to $100/20 = 5$. That is, the lens has a rated speed of f :5.

Most high-grade photographic objectives are equipped with adjustable aperture stops, commonly known as iris diaphragms. When this is the case, the speed, or light-gathering power, of the objective may be changed at will simply by changing the diameter of the iris diaphragm. In this way the denominator of the f/number equation given above becomes variable; therefore the speed of the lens is adjustable at the will of the user. For example, if the diaphragm is stopped down to 10 mm. instead of 20 the speed of the objective changes from a value of f:5 to a new value of 100/10 = f:10. Since the lens has been stopped down, thus decreasing the diameter of the aperture, we would expect it to be slower, that is, to gather less light. Consequently, a speed of f:10 is slower than a speed of f:5, the difference in speed being proportional to the change in area of the entrance pupil. Since the areas of circles are directly proportional to the squares of their diameters, it follows that the speeds of photographic objectives are inversely proportional to the squares of their f:numbers. Hence a lens operating at f:5 is four times faster than the same lens operating at f:10.

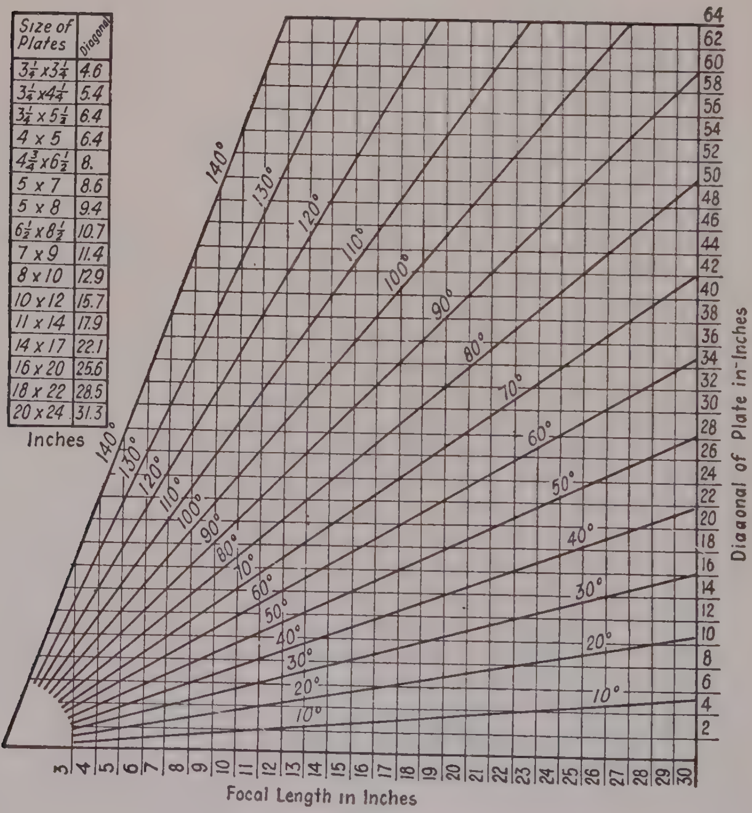
Although the f/number system is now universally used throughout the world, formerly lens speeds were rated on the U. S. (Uniform System). In the U. S. system, the numbers are directly proportional to the exposure required, f:4 being taken as unity. A comparison between the f/number system and the U. S. system is given below:

f/number	f/4	f/4.5	f/5.6	f/6.3	f/8	f/11	f/16	f/22	f/32	f/45
U. S.	1	1.26	2	2½	4	8	16	32	64	128
Relative exposure required	1		2		4	8	16	32	64	128

Experimental Determination of Relative Aperture.—When the focal length of a photographic objective is known, it is only necessary to determine the diameter of the entrance pupil in order to find its relative aperture. The diameter of the entrance pupil may easily be found experimentally by a process devised by A. Steinheil. After the camera is set on the infinity mark, the ground glass is removed and replaced by an exactly-fitting piece of cardboard which has a small circular hole about two millimeters in diameter at its center. Care should be exercised in fitting the piece of cardboard, since the hole at its center should coincide with the optical axis of the lens. In the darkroom a small piece of bromide paper is fitted inside the lens cap, and this is placed over the front of the lens with the emulsion side of the paper toward the lens. An incandescent lamp is now held behind the hole in the cardboard for a few seconds. A black circular disk will be found upon the bromide paper upon development, the diameter of this circle being equal to the entrance pupil of the objective. This will be seen readily by studying the course of rays from the small circular aperture in the cardboard. The f/number, or speed of the lens, is now readily found by dividing its focal length by the diameter of the black circle appearing on the bromide paper.

Angle of View.—The angle of view of any objective is the angle subtended by two lines drawn from the node of emergence to the corners of the plate in use. The shorter the focal length of the lens in relation to the size of the plate, the greater the angle of view and the more of the subject included from a given viewpoint.

It is often of advantage to be able to calculate the maximum angle of view for a given lens on a certain sized plate, and to render this a



Size of Plates	Diagonal
3¼ x 3¼	4.6
3¼ x 4¼	5.4
3¼ x 5½	6.4
4 x 5	6.4
4¾ x 6½	8.
5 x 7	8.6
5 x 8	9.4
6½ x 8½	10.7
7 x 9	11.4
8 x 10	12.9
10 x 12	15.7
11 x 14	17.9
14 x 17	22.1
16 x 20	25.6
18 x 22	28.5
20 x 24	31.3

Inches

Table for the Calculation of Angle of View simple matter we have reproduced a chart by which this information can be simply and rapidly secured.

The maximum angle of view possible with any lens depends upon the relation between its focal length and the size of the plate which it will cover with satisfactory definition. For a given size of plate, the shorter the focal length of the lens, the greater is the angle of view, while on the other hand, the larger the plate which a lens of given focal length will cover with sufficiently critical definition, the greater is its angle of view. Thus a lens of six inch focal length will include a much greater angle if used on a 5 × 7 plate than if used on a 4 × 5 plate. Most lenses, however, particularly if of high speed, will not cover satisfactorily a plate much larger than that for which they are designed unless considerably stopped down. A lens made to cover with satisfactory definition a field large in proportion to its focal length is termed a wide angle lens.

Exposure Correction Required when Lens is not at Infinity Position.—The f/number marked on the lens mount of any camera indicates the relative light gathering power of the lens for the infinity position only, i.e., when $v = f$. For other lens positions, as for example, when one is photographing an object at a distance of 6 feet, the f/numbers as marked are incorrect, and, therefore, an exposure correction should be made to compensate for this error. The amount by which the exposure should be corrected for this condition is given by the ratio v^2/f^2. To illustrate the use of this relation, consider the case where the lens has been racked forward from its infinity position by an amount equal to one focal length—as would be the case for copying at unit magnification. Under these conditions, $v = 2f$, hence, $v^2/f^2 = (2f)^2/f^2 = 4$. This indicates that four times the exposure is needed at unit magnification than for infinity. Hence, if a photoelectric exposure meter indicated the exposure to be 1 second at f/16, it would be necessary, at unit magnification, to give either 4 seconds at f:16 or to open up the lens to f:8 if the exposure time is kept at 1 second.

Depth of Field.—Theoretically, even a high-grade photographic objective is incapable of forming a sharp image of more than one plane in the object space. In practice, however, not only the subject focused upon appears sharp, but subjects somewhat nearer and those much farther away also appear tolerably sharp. The distance from the nearest to the farthest points that appear sharp is called the *depth of field* of the objective. The depth of field of a given lens depends upon (1) its focal length; (2) its relative aperture; (3) the distance of the lens from the plane focused upon; (4) the diameter of the permissible circle of confusion; and (5) the presence of various lens aberrations.

In general, the image created by even a theoretically perfect lens does not fall upon a flat plane unless the object photographed is a flat plane. Therefore, we must consider the image formed when photographing a three-dimensional object as also being three-dimensional.

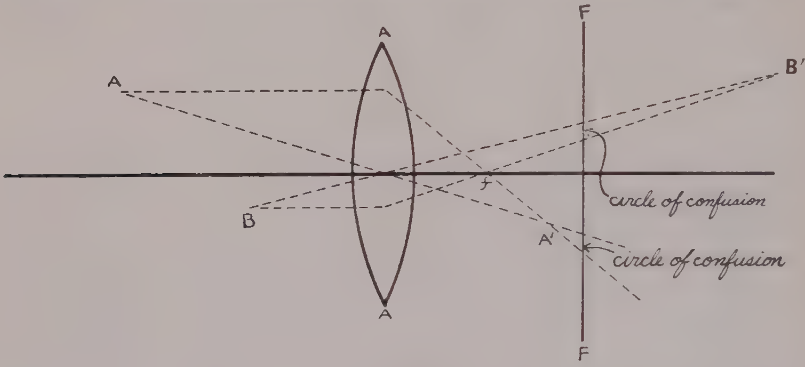


Fig. 65

For example, in Fig. 65 let us consider that A and B represent two points in the object being photographed. A lens AA forms images at these points as A' and B', respectively. It is obvious that no flat plane perpendicular to the optical axis can be drawn which will include both points A' and B'. Therefore, it is impossible to place a film in the image space which can record both of these points at the same time and still have the film orthogonal to the optical axis. If the film were located in some such plane as FF, then the images of points A and B in the film plane would be recorded as disks rather than points. A disk of this sort is called a circle of confusion.

If the circle of confusion is small enough, one is unable to visually distinguish it from a point. Therefore, the actual point image may fall slightly in front of, or slightly behind, the film without causing a blurred effect on the negative in the mind of the observer. Fig. 66 shows the imagery of two axial point objects A and B at A' and B'

Brown—Theory and Practice of Depth of Focus. Brit. J. Phot., **69** (1922), 492, 507, 521, 534.

Southworth—Numerical Expression for the Depth of Focus. Brit. J. Phot., **76** (1929), 483–486.

respectively. If the maximum permissible circle of confusion is represented by d, then the planes X' and Y' represent the limits within which the film may be placed without exceeding a circle of confusion greater than d. This permissible film range is known as the *depth of focus,* while the conjugate range in the object space is termed the *depth of field.* Hence in Fig. 66 the distance XY is the depth of field and the distance $X'Y'$ the depth of focus, provided the circles of confusion on the film do not exceed an amount which may be tolerated by the eye.

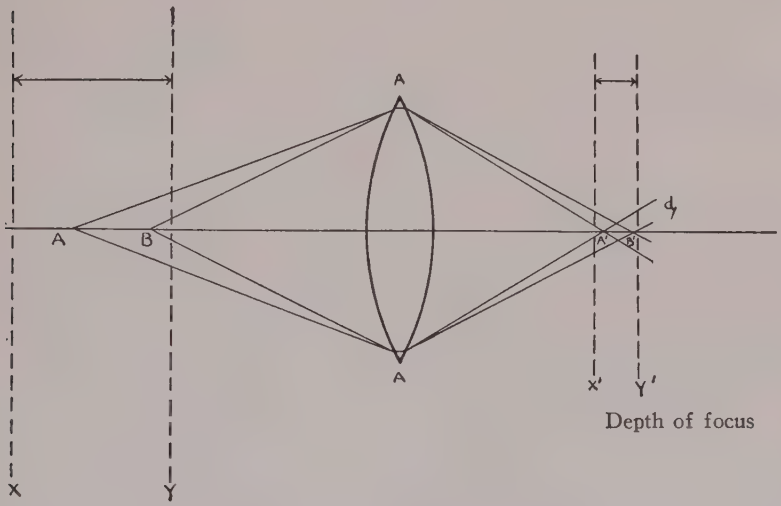


FIG. 66

Depth of Field and Hyperfocal Distance.—The manufacturers of photographic objectives usually allow a circle of confusion whose diameter equals 1/1000 of the focal length of the lens in computing depth of field tables. Hence, for a 2-inch lens the tolerable circle of confusion would equal 1/500 of an inch, while for a 10-inch lens the circle of confusion would be 1/100 of an inch. This method of selecting the permissible circle of confusion compensates automatically for the fact that the shorter focal length lenses are used on miniature cameras where enlargements are almost inevitably made from these negatives.

In computing depth of field tables it is customary to utilize the so-called *hyperfocal distance.* When a camera is focused on the hyperfocal distance, all objects within the range from infinity to a position half way between the camera and the hyperfocal point appear to be in focus. A lens is said to exhibit its maximum depth of field for a given aperture when it is focused upon the hyperfocal distance. A knowledge of the hyperfocal distance for a given lens at its various apertures prevents unnecessary stopping down in order to secure maximum depth of field. The hyperfocal distance of a given objective may be computed by means of the following equation:

$$H = \frac{F^2}{(f/\text{number})\ d}$$

where H represents the hyperfocal distance in inches, F the focal length of the lens in inches, and d the diameter of the circle of confusion in inches ($d = F$ divided by 1000).

After having computed the hyperfocal distance, the near and far distant points of sharpness may be computed in accordance with the following formulas:

$$\text{nearest point of sharpness} = \frac{Hx}{H + x},$$

$$\text{farthest point of sharpness} = \frac{Hx}{H - x}.$$

To illustrate the use of these formulas, consider the case in which a photograph is made using a lens having a relative aperture of f:8 and a focal length of 10 inches, the object being 20 feet from the camera and a circle of confusion of 1/100 of an inch being regarded as permissible. In this case,

$$H = \frac{F^2}{(f/\text{number})\ d} = \frac{10^2}{8 \times 1/100} = 1250'';$$

$$\begin{aligned}\text{nearest point of sharpness} &= \frac{Hx}{H + x} \\ &= \frac{1250 \times (20 \times 12)}{1250 + (20 \times 12)} \\ &= 201.8'' \\ &= 16' - 9''.\end{aligned}$$

$$\begin{aligned}\text{farthest point of sharpness} &= \frac{Hx}{H - x} \\ &= \frac{1250 \times (20 \times 12)}{1250 - (20 \times 12)} \\ &= 297'' \\ &= 24' - 9''.\end{aligned}$$

Hence, as measured from the camera, the depth of field extends from 16 feet 9 inches to 24 feet 9 inches and, therefore, the zone of sharpness extends 3 feet 3 inches in front of the object and 4 feet 9 inches beyond it. It will be noted that the depth of field is not equal on both sides of the object.

The point on which to focus in order to obtain sharp definition on two objects at different distances from the camera without unnecessary stopping down can be determined by a very simple calculation which usually can be done mentally. The rule is to multiply the two distances, double this, and divide by the two added together. Thus, if the two objects are placed 4 and 6 feet from the camera, the point on which to focus would be found as follows:

$$\frac{4 \times 6 \times 2}{4 + 6} = \frac{48}{10} = 4.8 \text{ ft.}$$

Focus on this distance using the lens at its largest aperture and then reduce the aperture until the two objects are sharp. By knowing the exact point on which to focus, the use of a stop smaller than absolutely necessary is avoided.[2]

Lens Aberrations.—The mathematical relations used to locate the image formed by a lens are based on the assumption that the marginal rays come to the same focal point as the axial rays. When an actual lens is examined in practice, however, it is found that this is not the case. The failure of all the rays to converge to a common point after refraction results in a lack of perfection in imagery which is referred to as lens aberration. In other words, the presence of aberrations causes object points to be imaged not as points but as small finite areas of light, the size of these areas being directly proportional to the magnitude of the aberrations present. It is obvious that the smaller these areas become (through skillful lens design) the sharper the resulting image. It, therefore, becomes the problem of the lens designer to so shape the lens surfaces that these aberrations are reduced to a minimum in order that the image may be as sharp as possible.

[2] Graphical methods of determining the point on which to focus: Collins, *Brit. J. Phot.*, **67** (1920), 659, 676. Abacus for Optimum Focusing Distance, *British Journal Photographic Almanac*. Browne, "Simple Depth Chart." *Brit. J. Phot.*, **70** (1923), 775.

LEE—Chart for Finding the Depth of Focus. Phot. J., **62** (1922), 229; Brit. J. Phot., **69** (1922), 135.

SALT—Graphic and Simple Method of Demonstrating Some Aberrations of Lenses. Brit. J. Phot., **76** (1929), 308.

The presence of aberrations in a lens arises from several different causes, each of which may be spoken of separately although in practice the aberrations seldom exist alone. The aberrations which are commonly considered separately are: spherical aberration, chromatic aberration, coma, astigmatism, distortion, and curvature of field.

Spherical Aberration.—Fig. 67 represents the type of image obtained with a lens having considerable spherical aberration. It will be noticed that the marginal, or rim, rays come to focus nearer the lens than the axial rays,—in other words, the rays passing through the lens do not cut the axis at a single point. In a single positive lens the rays farthest from the axis come to focus closer to the lens, while in a negative lens the opposite is true. Hence, the combination of a positive and negative lens of proper strength may be used to eliminate spherical aberration. Another but somewhat more expensive method of correcting spherical aberration is to form a non-spherical surface the shape of which will cause all the rays to come to a single point of focus. A single lens of this type is known as an aspheric lens. From this it is evident that spherical aberration is due to the surface of the lens being spherical.[3]

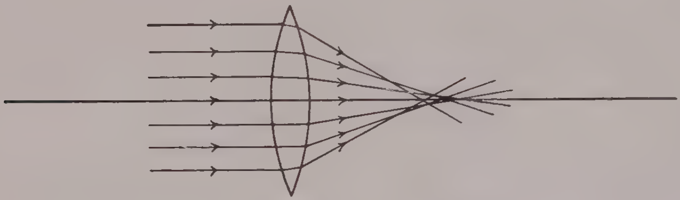


Fig. 67. Spherical Aberration

The combination of a positive and negative lens to neutralize spherical aberration is a common procedure used by lens designers to overcome this inherent difficulty encountered with spherical glass surfaces. In the manufacture of photographic objectives, it is common practice to adhere to plane and spherical surfaces and to minimize spherical aberration by the proper choice of radii of curvature for the lens surfaces. A plano-convex lens used with its convex surface toward the incident light gives far less spherical aberration than almost any other type of single lens, particularly where parallel light is incident upon the convex surface.

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[3] Aspherical surfaces are used to a limited extent in the manufacture of condenser lenses where the improvement in imagery justifies the large expense entailed by the handwork that must be done in shaping such a lens surface. This technique is usually resorted to only in those cases where the maximum amount of light must be passed by the condensing lens and one cannot afford to lose the rim ray component.

It is usually considered satisfactory if a photographic objective exhibits no more spherical aberration than an amount equal to approximately one-third of one per cent of its focal length. Therefore, in a 100-mm. lens marginal rays focusing at 3/10 of a mm. in front of the axial rays would be tolerated.

Chromatic Aberrations.—We have previously shown that the focal length of a single lens may be represented by the equation:

$$f = \frac{1}{(n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}.$$

As pointed out on page 71 the index of refraction n of any optical glass is different for light of different wave lengths. From this it follows that any single glass lens has a different focal length for each color of the spectrum. This effect is known as chromatic aberration. With a simple positive lens the focal length is shorter for blue light than for red, because all glasses exhibit a higher value of n for blue light than for red light. With a negative lens, however, the opposite is true and the focal length is shorter for red than for blue. Therefore, chromatic aberration may be corrected by making a compound lens of two separate lenses, one positive and the other negative, provided they are of the proper strength and correct indices of refraction. In practice, the positive lens is usually made of crown glass and the negative lens of flint. With flint the index of refraction varies by a considerable amount from color to color, while the effect is not so marked with crown glass. In design the negative flint lens is so made that its variation of focal length with color is sufficient to compensate for the focal length color variation in the crown lens. By using flint glass for the negative lens, the converging effect of the positive component is not entirely neutralized and the resulting combination is a positive lens in which chromatic aberrations have been eliminated. In practice, the curvature of the two adjacent surfaces of the two components are made the same so they may be cemented together with Canada balsam. This cement makes the two lenses a single unit eliminating the reflec-

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Herriott—A Method of Measuring Axial Chromatic Aberration in an Objective Lens. J. Soc. Mot. Pict. Eng., **20** (1933), 323–331.

tion losses which would be present at the inner surfaces were they separated.

Formerly, when photographic plates were only blue sensitive, the problem of chromatic aberration did not assume the importance that it does today with supersensitive panchromatic emulsions sensitive to light of all colors. Also, for color photography it is particularly important that the photographic objective be free from chromatic aberration to eliminate color fringing. Today the problem of correcting for chromatic aberration transcends in importance all other corrections if the lens is to be used for color photography.

A doublet lens consisting of a positive and negative element which have been achromatized to eliminate chromatic aberration is known as an achromat.

Astigmatism.—Fig. 68 indicates the manner in which an oblique parallel beam of light incident upon a single positive lens is brought to focus. When an oblique light beam of this nature is passed through a positive lens, a loss of perfection in imagery results known as astigmatism. The type of image formation can be understood best by considering the appearance of the image formed on a ground glass which is held in the neighborhood of the point of focus. If the ground glass is held at point A, the image is an erect vertical line; at an intermediate point the image is an ellipse. At a point midway between A and B the image is a circle, while at B the image again is a straight

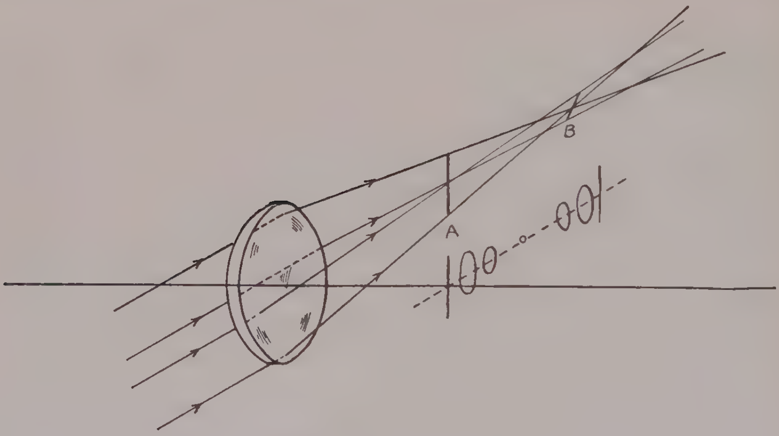

Fig. 68. Astigmatism

line but this time a horizontal one at right angles to the line image formed at point *A*. The thumb-nail sketch illustrates the type of images formed in the neighborhood of focus where astigmatism is present.

The effect of astigmatism upon the image of an object containing horizontal and vertical lines is interesting. If the negative plane is so located that horizontal lines are in focus, then vertical lines are out of focus and vice versa. In other words, either vertical or horizontal lines can be focused sharply, but both cannot be in focus simultaneously.

In practice, astigmatism is lessened by the use of compound lenses having glasses of properly selected indices and by using a combination of spherical surfaces which bear the proper relation to each other. It should be borne in mind that astigmatism is an off-axis characteristic, and when an image is being examined for astigmatic defects the marginal regions rather than the center should be scrutinized. A wire mesh screen photographed against a blue sky offers a very convenient subject to photograph when testing a lens for astigmatic defects. If astigmatism is present, the horizontal wires are sharp at one point of focus while the vertical lines are definitely out of focus. The reverse is true for a slightly different image plane.

Coma.—When a bundle of rays pass obliquely through a single lens, it frequently happens that the rays in the neighborhood of the image come to a focus in approximately the same plane but fall at different points instead of being superimposed. When this occurs, the lens is said to suffer from coma.

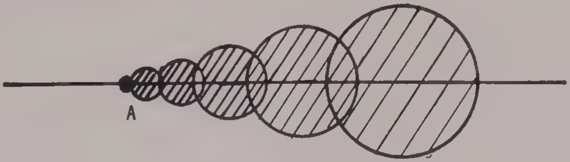

FIG. 69

Figure 69 shows a comatic image. For the sake of clearness let us consider the lens to be divided into several circular concentric zones. The image formed by the zone nearest the axis is represented by the small circle at *A*. The image formed by each successive zone is a slightly larger circle of confusion and displaced to the right. It is evident that most of the light is concentrated in the region of the smallest circle, and as a result the image is brightest at its small end and falls off in intensity toward the larger end. The resemblance of this image to that of a comet is responsible for the name of this aberration.

Coma is sometimes referred to as the spherical aberration of oblique rays. Like astigmatism it occurs at the margins of the image field rather than at its center. In considering both astigmatism and coma it should be remembered that only the simplest possible case has been presented here, and we have assumed that all other aberrations are absent. For a further discussion of this subject the reader is referred to any of the many reliable texts on optics. The elimination of coma from a compound lens is accomplished by cementing together single negative and positive lenses each of which suffers from coma but in the opposite sense. In practice, it is almost impossible to correct for coma in all the circular zones of the lens. Therefore, a lens is said to be coma free when it exhibits no coma for some particular zone and the amount of coma in other zones is reduced to a negligible amount. A doublet lens which is free from both spherical aberration and coma for some particular point is referred to as an *aplanat*.

Curvature of Field.—Curvature of field and distortion differ fundamentally from the four aberrations already discussed in that they do not pertain to the perfection of the imagery of an object point. Curvature of field and distortion refer to the relative location of different image points as compared with the relative location of the object points. In other words, curvature and distortion refer to the spacial arrangement of the image points rather than to their degree of perfection. When the image points of a plane object lie upon a curved surface rather than a plane, the lens is said to suffer from curvature of field. Fig. 70 represents such a condition. This type of aberration is particularly disadvantageous in photographic objectives since photographic surfaces are, in general, confined to a plane surface, thereby making it impossible to focus the entire object sharply upon the sensitive material. Curvature of field may be corrected to some extent by using a combination of two lens elements of

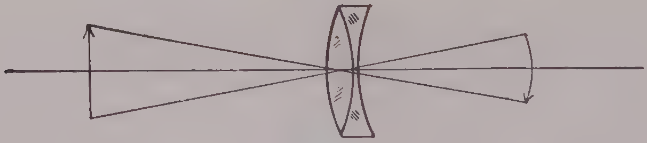

Fig. 70

proper indices. Much more can be done, however, to minimize this aberration by separating the elements and placing a diaphragm of the proper size between them. An excellent example of this may be seen by examining the field of a single lens and comparing it with the field produced by a combination of two lenses, one positive and the other negative, the combination, however, having the same focal length as the single lens. A stop, or diaphragm, located at a suitable distance in front of a simple meniscus lens tends to flatten the field quite effectively. This procedure is known as artificially flattening the field, a technique employed in the manufacture of many inexpensive lenses. This effect is produced by the action of the diaphragm in causing the rays forming the image at the edge and the center of the field to traverse different portions of the lens.

Distortion.—When a square object is imaged in the manner shown at *A* or *B* in Fig. 71 the lens producing this image is said to suffer from distortion. Distortion arises from the fact that the linear magnification varies with the distance from the axis. If the magnification is greater at the margin of the field of view than at its center, as shown at *A*, positive distortion results; while if the magnification is greater at the center of the field than at its edges, negative distortion results, as shown at *B*. The terms *pin cushion* and *barrel* distortion are usually associated with the type of images formed at *A* and *B* respectively.

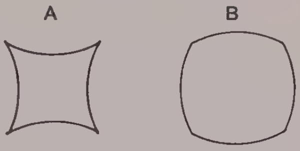

Fig. 71. Types of Distortion

The type of distortion as well as its magnitude depends largely upon the position of the diaphragm. Fig. 72 illustrates the effect of diaphragm location in the case of a plano-convex lens. It will be noted that when the diaphragm is placed in front of the lens, barrel distortion results, while if the diaphragm is located behind the lens, pin cushion distortion is shown. The third diagram shows an effort to combine these two opposite errors. When the diaphragm is placed at the proper point between the two lenses, the positive error of the first lens will be neutralized by the negative error of the second and a rectilinear, or non-distorted, image is produced. In a well designed photographic objective, the amount of distortion seldom exceeds 3/10 of one per cent, even for angular distances as great as 30 degrees from the axis. Symmetrical objectives of the rapid rectilinear type exhibit little or no distortion since they are constructed symmetrically about the diaphragm.

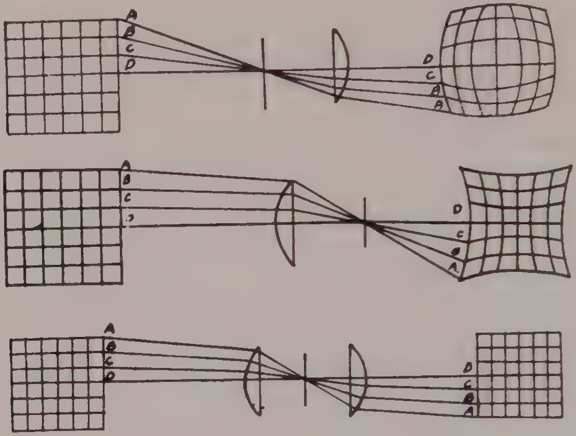

FIG. 72. Effect of Position of the Diaphragm on the Type of Distortion

Balancing Aberrations in Lens Design.—In any specific photographic objective it is impossible to eliminate certain imperfections which of necessity must be present,—in fact no optical system has as yet been devised which eliminates even a single aberration completely for even a single position of the object. The best that the lens designer can do is to balance the aberrations to produce a lens which is useful for the purpose intended and at the same time not requiring too many elements thereby making it difficult to manufacture. Usually the lens designer develops a lens to eliminate, insofar as possible, those aberrations which would be most detrimental. With this in mind, he so selects the components, and so shapes them, that these aberrations will be reduced to a minimum and at the same time none of the others will reach such a magnitude as to become objectionable. Usually, if the demands of the user are such that the relative aperture and size of field to be covered are not excessive, the aberrations can be so controlled that the quality of the image is limited solely by the finite nature of a wave length of light. Even in the case of wide-angle, high-aperture lenses, the designer usually produces an objective which is superior in its image formation qualities to the skill of the user.

Resolving Power.—As previously pointed out, a study of the nature of light reveals it to be of a wave character. It is a commonly observed phenomenon that waves, for example, ocean or water waves, bend around the end of a breakwater thereby invading that portion of the water surface which would normally be completely sheltered if the waves travelled only in straight lines. An opaque body, such as a diaphragm or stop, may be considered as an "optical" breakwater sheltering those areas behind it from the intrusion of light waves. A careful study of the action of lens diaphragms reveals, however, that a certain amount of the light is bent around their edge and thereby invades that portion where normally no light rays would be expected.

Since the wave length of light is extremely short, the extent to which light rays are bent around a diaphragm is slight, but still is sufficient to affect the quality of the image, particularly when the diaphragm is small. This phenomenon is referred to as *diffraction.* The diffraction pattern produced by a lens is shown in Fig. 73. The center spot represents the legitimate image which would be produced alone were no diffraction present. However, as a result of diffraction, the image is surrounded by a series of concentric rings which gradually fall off in intensity. As the size of the diaphragm is increased, these diffraction rings tend to disappear. However, on the other hand, as the lens is "opened up," other aberrations enter in to impair the quality of the image. Therefore, to secure optimum sharpness, the lens aperture must be small enough to minimize the normal lens aberration and yet not so small as to introduce serious diffraction. For this reason, it is usually found that with a given photographic objective, say, for example, an f:4.5 anastigmat, maximum sharpness is secured when operating at some intermediate aperture such as f:11 rather than by stopping down to the smallest possible diaphragm, as for example, f:32.

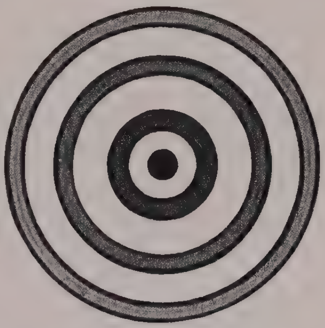

FIG. 73. Diffraction Image

The so-called *resolving power* of a lens may be determined by viewing two closely adjacent point light sources through the lens. As the light sources are brought closer and closer together, a condition arises where they are no longer distinguishable as two separate points of light, and under these conditions the resolving limit of the lens is said to have been obtained. The angle subtended by two such points, which are just far enough apart to permit resolution, is commonly referred to as the resolving power of the lens, or the limit of angular resolution.

When the normal lens aberrations are reduced to such an extent that they do not enter into the consideration of resolving power, and if the rays of light incident upon the lens are parallel, then the angle of resolution in seconds may be determined by the following formula:

$$a = \frac{5}{d}$$

where α = angle of resolution in seconds,
d = diameter of lens, inches.

If other lens aberrations are present, the resolving power will be less than that indicated by the above formula. The phenomenon of diffraction sets a limit to the sharpness of imagery which can be secured from a lens of given size. Beyond this limit, it is impossible to go.

The term " resolving power " is many times used loosely to define the limit of a given photographic objective to record fine detail in an object. When used in this sense, it is of no consequence whether this limit is imposed by diffraction or by lens aberrations.

Loss of Light in Lenses.—The speed of a lens is usually denoted by its f/number which is the ratio between the focal length of the lens and the diameter of its entrance pupil (see page 86). A little thought will reveal, however, that this law is not absolutely valid since it refers to the quantity of light entering the lens and takes no account of the loss of light by absorption in the glass or by reflection at the glass air surfaces. The light lost by absorption is usually negligible since only about two or three per cent of the incident light is lost per centimeter thickness of glass.

The loss of light by reflection is of much greater importance. The magnitude of this loss can be calculated by the equation given by Fresnel which is to be found in any treatise on optics.

Dr. A. Klughardt made such a computation for several photographic objectives, ranging in aperture from f :2 to f :11. The following table states the results of Dr. Klughardt's computation.[4]

It is readily apparent that the magnitude of the reflected light loss increases rapidly with the number of glass surfaces in the lens. It, therefore, follows that an uncemented lens would be slower than a cemented lens having the same relative aperture. To illustrate this,

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[4] Photo-Barse, 7 (1925), 414.

Type	Lenses	Reflecting Surfaces	Cemented Surfaces	Reflection Loss	Total Loss
Periscope, f : 11	2	4	–	16%	20%
Dagor, f : 6.8	6	4	4	18%	22%
Triplet f : 3.5	3	6	–	29%	32%
Tessar f : 4.5	4	6	1	28%	33%
Dogmar f : 6.8	4	8	–	37%	40%
Ernostar f : 2.0	6	8	2	38%	48%

consider the comparison between the Dagor f :6.8 and the Dogmar f :6.8 as listed in the above table. With the Dagor objective, 78 per cent of the incident light reaches the film, whereas with the Dogmar objective only 60 per cent of the light reaches the film. Hence, the increase in exposure necessary when using the Dogmar would be as 60 : 78 or 1 : 1.3. In other words, the exposure with the Dogmar must be 1.3 times that with the Dagor under like conditions.

Diminution in Illumination of the Image with the Distance from the Axis.—Let us now consider the distribution of light intensity over the image area, that is, the decrease in light intensity toward the margins of the image. This effect can easily be seen by exposing a sufficiently large plate toward a white background so that the whole circle of illumination and the falling off in intensity therein appears on the plate. A fair percentage of the decrease in marginal image brilliancy is dependent upon the natural decrease in intensity of extra-axial light, a situation which cannot be avoided by any means of correction. To illustrate, let us designate the intensity of illumination at the center of the image by I_0 and that at the margin by I. According to the Lambert's law of photometry $I = I_0 \cos^4 \theta$, where θ is the angle that the marginal ray makes with the optical axis of the lens. In the usual type of photographic objective this angle seldom is greater than 35 to 40 degrees.

θ	0°	10°	20°	30°	35°	40°
I	100%	94%	78%	56%	45%	34%

Hrdlicka—Measuring the Effective Illumination of Photographic Objectives. J. Soc. Mot. Pict. Eng., **14** (1930), 531–533.

Moffitt—The Light Absorbed by Lenses. Phot. Journal of America, **59** (1920), 411.

Odencrants—The Experimental Determination of the Luminosity of Photographic Objectives. Nord. Tids. Fot., **9** (1925), 21; S.I.P., **5** (1925), 87.

Zschokke—Factors Other than Aperture in the Rapidity of a Lens. Brit. J. Phot., **59** (1912), 823.

It will be observed that this loss increases very rapidly as the angle subtended by the plate at the lens increases. Unfortunately, there is no really practical means to prevent this decrease.

In some types of objectives a still further loss of light is incurred by vignetting of the marginal rays by the lens mount itself. In general, this loss of light becomes smaller the closer together the lens elements are placed. Unfortunately, it is not always possible to obtain a maximum aberration correction and at the same time produce a compact lens.

Vignetting of marginal rays by the lens mount, together with the unavoidable decrease in marginal intensity due to the cosine law, may result, in extreme cases, to an intensity of illumination at the margins of from 15 to 25 per cent of the center illumination.

The Contrast of Photographic Lenses.—Ideally, a photographic objective should be capable of reproducing accurately the full range of brightness in the object photographed. In order to do so, it is necessary that each area in the image receive light only from the corresponding area in the object. When other than true image-forming light falls upon the image area, an adulteration of contrast occurs and the photographic reproduction is of lower contrast than that possessed by the original subject.

The factors which most commonly contribute to the presence of extraneous light in the camera are listed below.

Factors Affecting the Contrast of a Lens

1. Camera leaks light.	Avoidable by proper construction and care of the camera.
2. Reflection of light at the glass-air surface of the lens.	Cannot be avoided but can be reduced by proper design of the objective.
3. Reflection of light by bright metallic surfaces of the lens mount, lens diaphragm, and camera interior.	Difficult to control and of rather considerable magnitude.
4. Diffusion of light produced by foreign particles on the glass surfaces. (Finger prints, dust, etc.)	Principally avoidable by keeping the lens clean.
5. Diffusion of light by foreign material within the glass.	Usually of too small a magnitude to be of any practical consequence.

Jones and Tuttle—Effect of Projection Lens Flare upon the Contrast of a Motion Picture Image. Trans. Soc. Mot. Pict. Eng., 25 (1926), 153–166.

Tuttle and White—Factors which Affect the Contrast of a Lens Image in the Motion Picture Camera. Trans. Soc. Mot. Pict. Eng., 11 (1927), 591–599.

Rheden—Reflections in Lenses. Phot. Rund. (1921), 101.

In a properly designed objective, the lens flare produced by light reflected from glass-to-air surfaces is small, particularly if the objective consists of not more than three components. In fact, several four piece anastigmats are on the market which possess so little flare that they can be used without fear of seriously menacing image quality. However, all six-piece, large aperture lenses of short focal length exhibit enough flare to make this a primary consideration.

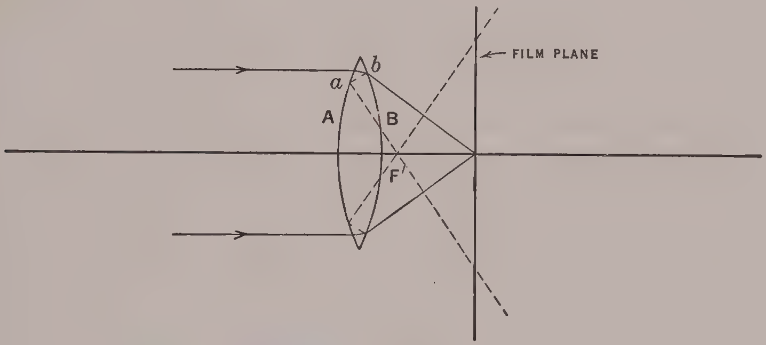

FIG. 74. Reflection of Light in the Objective

Figure 74 shows a simple lens with parallel light incident upon it from the left. The legitimate image of the infinitely distant source of light occurs at *F* while a spurious image produced by lens flare occurs at *F′*. The intensity of the image *F′* is much lower than that of *F*, since *F′* is comprised of only that portion of the light which is reflected at both surfaces *A* and *B* in the manner shown in the figure. The ray *b-a* is only about 4 per cent of that contained by the original ray from the object and the ray *a-F′* is only about 4 per cent as intense as ray *b-a*. Hence, ray *a-F′* is about 4 per cent of 4 per cent or 1/625 the intensity of the legitimate image *F* and the primary flare image *F′* is as 625 is to 1. The position of *F′* is entirely dependent upon the curvature of the lens surfaces and upon the refractive index of the glass. When *F′* lies close to the negative plane, an intense flare spot results which seriously affects the contrast of the image of this part of the object. When, as in the case shown in Fig. 74, *F′* falls at a considerable distance from the negative plane, the flare light is distributed over a large portion of the image area and tends to reduce the contrast of the image as a whole rather than to build up an intense flare spot.

CHAPTER IV

PHOTOGRAPHIC OBJECTIVES

Introduction.—This chapter is designed to provide a concise summary of the principal types of photographic objectives in use today. No attempt has been made to make it exhaustive, nor to include constructional details which would be of interest only to the designing optician. A bibliography has been included which it is believed will meet the needs of those requiring more extended and detailed information.

Single Lenses.—Single uncorrected lenses are seldom used today except on the very cheapest box cameras. A single lens cannot be corrected in any way and consequently sharp definition can be obtained only with a small diaphragm. As the visual and photographic images do not coincide, the single lens is suitable only for box cameras or those focused by scale.

The meniscus form is usually employed since it has a larger useful field than a biconvex lens.

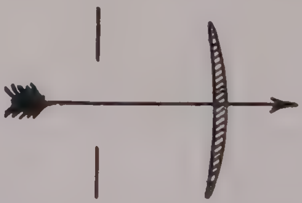

FIG. 76. Wollaston's Meniscus

Single Achromatic Lenses.—The usual form of single achromatic lens consists of two cemented menisci, the positive (collecting) lens being next to the diaphragm and consisting of crown glass while the rear lens is negative (dispersing) and consists of flint glass (Fig. 77). This construction appears to be due to the English optician Grubb[1] and results in better spherical correction and a larger field than the combination of a biconcave and biconvex element used in the earlier single lenses of Chevalier and his successors. A single achromatic lens of three cemented glasses having superior correction and an aperture of f:14 was introduced by Dallmeyer in 1864.[2] The construction is now obsolete.

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[1] B.P. 1968 of 1857.

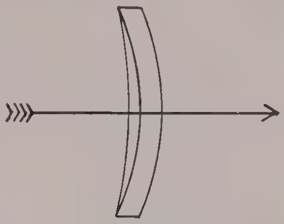

FIG. 77

On some box, and other fixed focus cameras, provision for photographing nearby objects is made by mounting a simple negative or positive lens of low power in front of the diaphragm in such a way that it can be readily shifted to one side when not required. If the front lens is negative, it is removed and the rear lens used alone when photographing nearby subjects. With a low power positive lens, these conditions are reversed and the front lens is used only for nearby subjects.

Double Objectives.—Simple double objectives of the type shown in Fig. 78 are used frequently where an inexpensive lens having a larger aperture than a single lens is desired. This construction results in a lens free from distortion, a flatter field and better spherical correction than the simple meniscus lens. The relative aperture is usually about f:11.

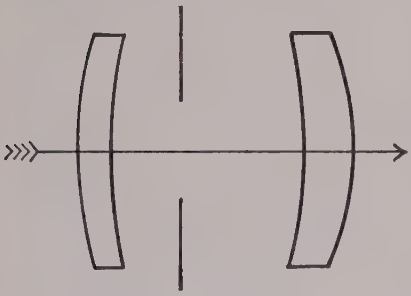

FIG. 78. Doublet F/11

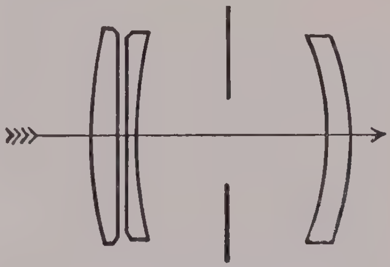

FIG. 79

A modification of the simple doublet is shown in Fig. 79. In this, the front element consists of a positive and negative component, the distance between the two being adjustable at will. Since the focal length of the complete lens depends upon the separation of the two components of the front element, focusing may be accomplished by screwing the front element of the lens in or out so as to vary the separation between the two.

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[2] B.P. 2539.

Soft-Focus Lenses.—Lenses corrected partially for spherical or chromatic aberration in order to produce a diffused or "soft-focus" image are used frequently by pictorialists who object to the sharp definition of a fully corrected lens. Objectives of this type take several constructional forms. A number, such as the Spencer *Portland,* the Pinkham Smith *Synthetic,* the Struss Pictorial, the Gundlach and the *Dallmeyer-Banfield* are single lenses. In most cases, the objectives are corrected for chromatic but not completely for spherical aberration; the undercorrection of the latter results in the diffused image characteristic of such lenses.

The *Plastigmat* of Bausch & Lomb and the *Verito* of Wollensak (Fig. 80) are of unsymmetrical construction, the front component consisting of a single lens and the rear a cemented doublet resembling a single landscape lens. In the case of the Verito, the single element may be used alone, thus obtaining a focal length approximately twice that of the complete lens. Both lenses are corrected for chromatic aberration and there is no focus difference. The degree of diffusion is controlled by the diaphragm. The maximum aperture of the Verito is f:4; the Plastigmat f: 5.6.

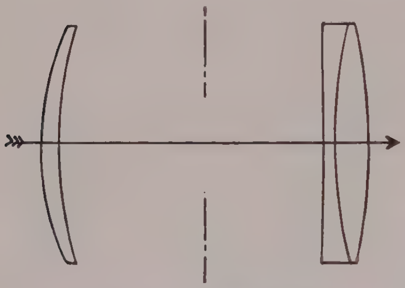

Fig. 80. Wollensak Verito

The Gundlach *Hyperion* and the Dallmeyer *Mutac* are similar in design to the aplanat or rapid rectilinear and the front and rear components may be used separately thus providing lenses of three different focal lengths. The maximum aperture of the Hyperion is f:4 and that of the Mutac f:4.5. In both cases, the diffused image is due to the presence of spherical aberration.

The *Dallmeyer-Bergheim* is a variable magnification teleobjective of the soft-focus type and consists of two simple lenses, the front positive and the rear negative. The equivalent focal length (degree of magnification) is regulated by altering the separation of the two lenses. The relative aperture varies with the degree of magnification from f:3.5 to f:20. The degree of diffusion is regulated by the diaphragm. The objective is not corrected for chromatic aberration, hence, a correction must be made after focusing.

In a number of cases, anastigmatic lenses intended particularly for portrait work and Petzval-type portrait lenses are designed in such a way that a diffused image may be obtained when desired by altering the position of one of the elements of the lens.

The Rapid Rectilinear or Aplanat.—Historically, this objective is interesting as the first well corrected symmetrical lens covering a wide field at a comparatively large aperture.[3] It has, however, been almost completely supplanted in recent years by anastigmatic lenses of the simpler constructions, since these are no more difficult to manufacture and possess an astigmatically flattened field with superior definition and, frequently, a larger aperture.

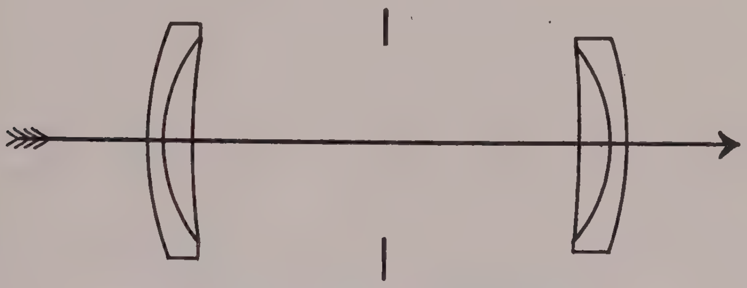

FIG. 81. The Aplanat or Rapid Rectilinear

The Aplanat and Rapid Rectilinear were calculated independently by Steinheil, of Munich, and Dallmeyer, of London, in 1866 and had an aperture of f :8. Later, objectives of larger aperture, but covering a smaller field, were introduced for portrait work.

Portrait Lenses.—Many portrait lenses in use today are based upon the Petzval construction, so called for its calculator Josef Petzval. The original Petzval construction (Fig. 82) consisted of a cemented biconvex and a biconcave lens in front of the diaphragm and a rear element of two separate lenses, the first a negative meniscus with its convex side facing the diaphragm and a double convex lens, the air space being a meniscus acting as a negative lens. An improvement in the spherical correction of the construction was effected by Dallmeyer in 1866 by reversing the glasses of the rear element. Lenses of the Petzval type now on the market are based in general on the Dallmeyer modification.

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[3] A double objective in which the arrangement of glasses is the same on both sides of the diaphragm is said to be of symmetrical design. Such objectives are usually so designed that the front and rear components may be used separately at smaller apertures. In this case, the complete objective affords a choice of at least two and frequently three focal lengths when the single elements are used.

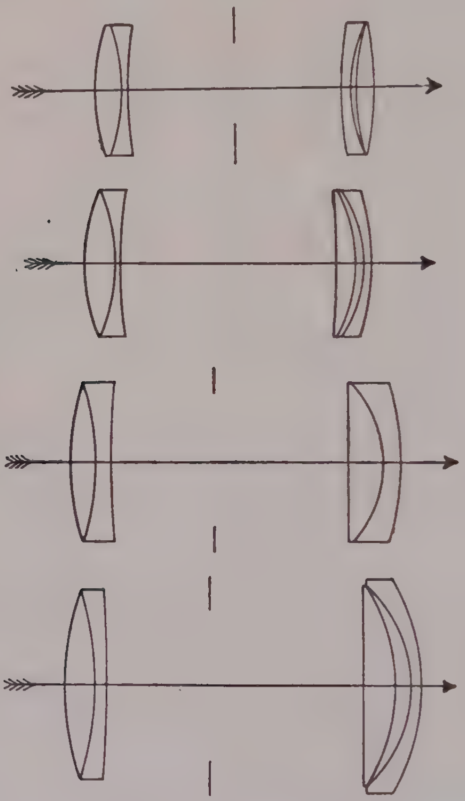

FIG. 82. Petzval's Portrait Objective and Its Modification

The Petzval construction is free from distortion and is chromatically corrected but covers a very small field, has a decidedly curved field, and, owing to its length, has considerable vignetting or diminution in the illumination of the marginal portions of the image. Practically, it is suitable only for portraiture or for work requiring a small image field.

Simple triplet constructions are also used for portrait objectives.

Usually no attempt is made to secure a high degree of correction in such cases; the aberrational errors remaining, are so controlled as to produce a "plastic" image. The Sigmar (f:4) of Bausch & Lomb and the Hypar of Goerz (f:3.5) are of this type. The character of the image is intermediate between that of fully corrected and soft focus lenses.

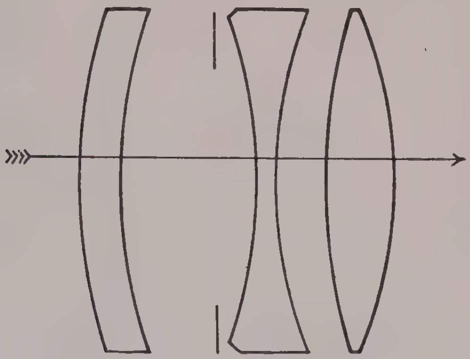

FIG. 83. The Sigmar of Bausch & Lomb

Conditions Necessary for the Simultaneous Correction of Astigmatism and Spherical Aberration.—The conditions necessary for the simultaneous correction of astigmatism and spherical aberrations have been summarized by R. Steinheil as follows:[4]

"An objective may be corrected for spherical aberration if two media are separated by a convex surface turned towards the medium of higher refraction; for astigmatism if the surface is concave to the medium having the higher refraction."

Thus, in Fig. 84 *A* and *C* are flint glass lenses of high relative dispersion and *B* and *D* are of crown glass with low dispersion. In the lens at the left, the cemented surface is convex to the medium of higher refraction, thus correcting for spherical aberration, while in the lens at the right, the cemented surface is concave to the glass having the higher refraction, the condition necessary for the removal of astigmatism.

Simultaneous correction for both spherical aberration and astigmatism, therefore, involves the employment of one or more surfaces, which may or may not be cemented surfaces, concave to media having a higher refractive index and other surfaces convex to media with higher refractive index.

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[4] *Eder's Jahrbuch*, 1897. "Origin and History of the Orthostigmats."

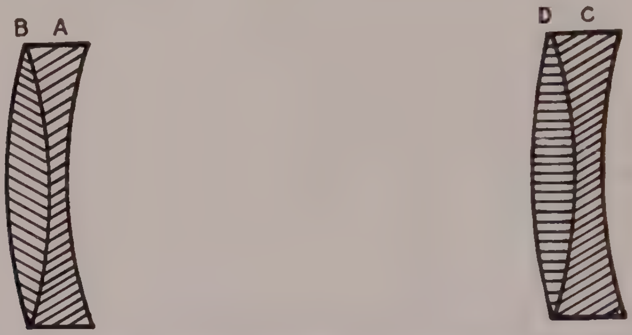

FIG. 84. Illustrating Condition Necessary for Correction (*a*) of Spherical Aberration and (*b*) Astigmatism

For many years it was impossible to satisfy these conditions as, in all the varieties of optical glass then available, the dispersion increased with the refractive index.

After the introduction of Jena glass, it became possible to make the collecting lens of glass having higher refraction and lower dispersion than the dispersing lens and thus secure astigmatic correction. The old achromat made of ordinary crown and flint could be corrected spherically but not astigmatically; the new achromat, while corrected astigmatically, cannot be spherically corrected. However, by combining the ordinary crown and flint of the old achromat with the barium crown glass of the new achromat, it became possible to correct both astigmatism and spherical aberration in the same lens. By combining two such achromats both of which are individually corrected to form a symmetrical objective a larger aperture becomes possible together with correction for curvature of field, coma, and distortion. This is the principle followed in the construction of most of the symmetrical lenses as the Goerz Double Anastigmat or Dagor, the Voigtländer Collinear, Turner-Reich Anastigmat, etc. The other method is to use two dissimilar combinations, one of which is spherically corrected while the other is astigmatically corrected; the two when placed on opposite sides of the diaphragm form an unsymmetrical objective which is completely corrected as a whole but not individually. This is the principle followed in the construction of most of the large aperture anastigmats.

Symmetrical Cemented Objectives Composed of Three Glass Components.—The conditions necessary for the correction of both astigmatism and spherical correction may be satisfied in a single objective consisting of three cemented lenses. Such an objective may take several forms. (Fig. 85).

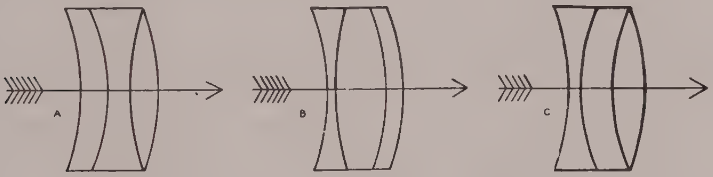

FIG. 85. Forms of Three Glass Elements

In the construction shown at the left, the indices of refraction of the three glasses increase from left to right; i.e., in the direction of the incident light. Hence, the first cemented surface is convex to the glass of lower refraction, meeting the condition for the correction of spherical aberration. The second cemented surface is convex to the glass of higher refraction and thus satisfies the requirement for astigmatic correction. Consequently, correction for both is secured by the opposition of the two cemented surfaces in an objective composed of only three cemented lenses.

Well designed objectives of this type give satisfactory definition at an aperture of about f:12.5. The combination of two such objectives on opposite sides of the diaphragm to produce a symmetrical objective enables the aperture to be increased to f:6.8, or even larger, if the complete objective is designed to cover a somewhat smaller field.

This construction is especially noteworthy for the excellent definition of both the single and complete objective and for the comparatively wide angle (70–80°) covered sharply by the double objective, particularly at a small stop.

The best known objective of this type is the Goerz *Dagor*;[5] other lenses based upon this principle are the Meyer *Aristostigmat*, the Wollensak Velostigmat Series I, the Schneider *Symmar*, Plaubel *Double Orthar*.

The construction shown in *b* of Fig. 85 consists of two negative lenses, one having a lower the other a higher refractive index than the interposed positive lens. In this case, the arrangement of cemented surfaces is reversed and the indices of refraction decrease in the direction of the incident light. An objective of this type has been made for years by Watson of London as the *Holostigmat* in two series, one with a relative aperture of f:4.6 and the other f:6.1; the single elements of both series may be used alone. The Steinheil *Satz-Anastigmat* is similar in design.

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[5] A special Dagor having a relative aperture of f:8 and an angle of 100° is made for wide angle work. B.P. 209,093 of 1922; *Brit. J. Phot.*, 1924, 71, p. 344.

The construction shown in *c* of Fig. 85 consists of a meniscus lens of low refraction between a double convex positive lens of high refractive index and a double concave negative lens of medium refraction. The Voightländer *Collinear* and the Steinheil *Orthostigmat* are the best known objectives of this type.

The Four Glass Cemented Element.—This design represents in effect the combination of the old achromat and a new achromat, made possible by the glasses produced at Jena, which enabled the astigmatic correction to be made.

This construction, because of the increased number of surfaces at the disposal of the designer, is especially noteworthy for the high degree of correction and for the large flat field, but is not suitable for large aperture objectives.

The *Protar,* Series VIIa (Fig. 86), of Zeiss is perhaps the best known objective of this type; among others may be mentioned the *Combinable* of Ross. The single elements of the former have an aperture of f:12.5; the double lens f:7.7. The relative aperture of the Ross Combinable is f:11 for the single lenses and f:5.5 for the double objective.

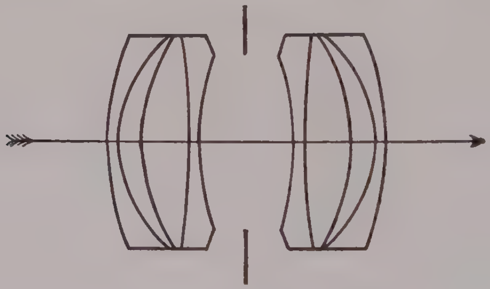

FIG. 86. Protar, Series VII*a*

The Cooke Series XV convertible anastigmat consists of two 4 lens components having the same general configuration as that developed by Rudolph except that an air space separates the second and third lenses (Fig. 87). The single components have a relative aperture of f:11 and are excellently corrected. The double objective formed of two such components has a relative aperture of f:6.8. Due to its excellent color correction, it is widely used by commercial photographers for color work.[6]

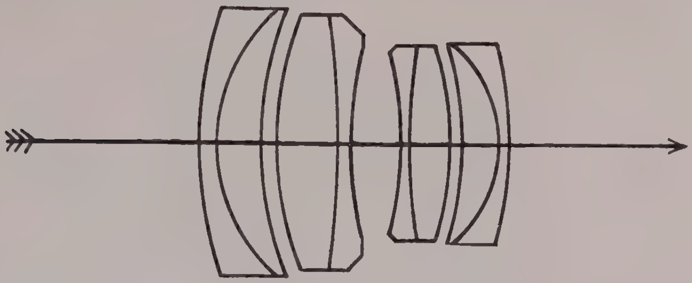

FIG. 87. Cooke Series XV Convertible Anastigmat

The five-lens cemented element is an outgrowth of an earlier three-glass lens of the rapid rectilinear type. To this earlier lens, a new achromat, made possible by the Jena glasses, was added for the correction of the astigmatic errors of the older lens. This construction increases the surfaces at the disposal of the designer and makes possible an exceptional degree of correction for the single element. The best known objective of this type is the *Turner-Reich* (Fig. 88).

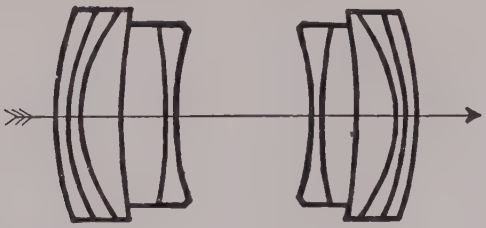

FIG. 88. Five Glass Element (Turner-Reich Anastigmat)

An alternative design (Fig. 89) consisting of three negative lenses enclosing two positive lenses was patented by Von Hoegh for the firm of C. P. Goerz.

Development of Lenses with Air-Spaces from the Three-Glass Element.—In a cemented element of three lenses, anastigmatic flatness is obtained and spherical aberration corrected by the use of two cemented surfaces, one of which is collective, the other dispersive in effect. If, in computation, the necessary power of refraction of the central lens is reduced until it becomes unity (i.e. equal to the refractive index of air), a two glass element may be produced which satisfies the conditions necessary for the correction of spherical aberration and astigmatism, since one surface is concave to a medium having a lower refractive index, namely air, while the other is convex. Objectives of this type were introduced by Goerz, from calculations by

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[6] B.P. 376,044 of 1932.

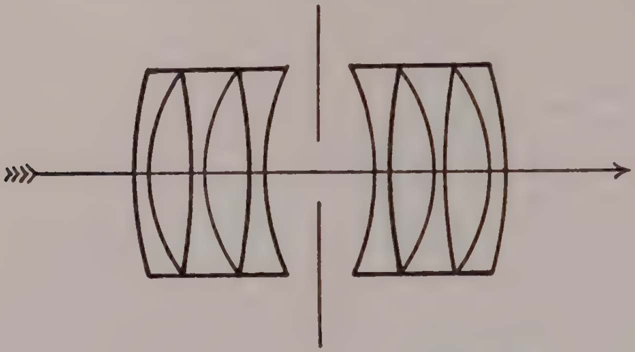

FIG. 89. Goerz Five Lens Cemented Element

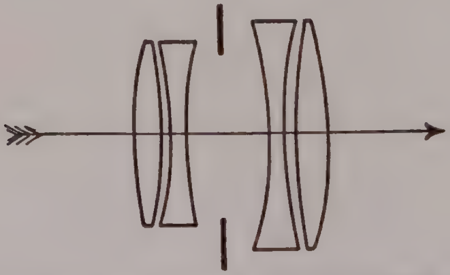

FIG. 90. Objective with Air Spaces as Developed from the Three Glass Cemented Element

Von Hoegh, as the *Celor* and *Syntor;* the first with a maximum aperture of f :4.5 and the latter, designed for hand camera use, with an aperture of f :6.8. With this construction, however, full comatic correction is impossible unless the symmetrical design is departed from, and the Celor and Syntor are no longer made.

A later introduction, known as the *Dogmar,* in which the symmetrical construction has been departed from, is still made. It has an aperture of f :4.5 and the single elements may be used separately at f :.32.

Triplets with Cemented Rear Element.—Triplet lenses of this type (Fig. 91) are not derived from the anastigmat triplet of H. D. Taylor but in an entirely different manner.

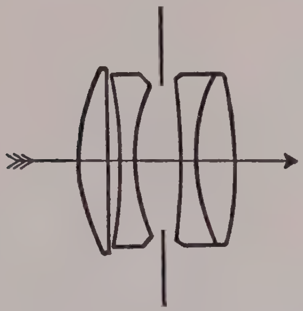

FIG. 91. Triplet with Cemented Rear Element

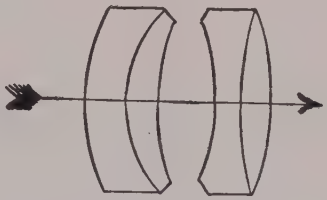

FIG. 92. Early Unsymmetrical Anastigmat of Paul Rudolph

Several years after he had patented his first Protar lens (Fig. 92), Rudolph realized the advantages to be gained from the substitution of air spaces for cemented surfaces. In 1899, he patented several forms of such an objective, one of which was introduced commercially by Carl Zeiss of Jena as the *Unar* (Fig. 93).

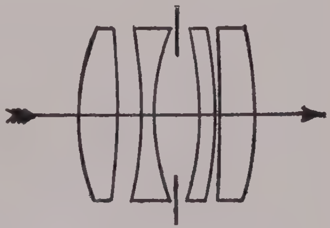

FIG. 93. The Unar of Rudolph

In this, the astigmatic and spherical corrections are made by the surfaces facing the air spaces rather than by cemented surfaces. The use of air spaces increases the number of surfaces at the disposal of the designer and thus enabled the aperture of the objective to be increased to f :6.

In 1902, Rudolph patented a triplet in which the rear element was a cemented doublet. This was introduced commercially by Carl Zeiss of Jena as the *Tessar.*

The Tessar may be described as a combination of the early Protar and the Unar. It consists (Fig. 91) of four lenses divided into two groups which are separated by the diaphragm. The first group contains a collecting and a dispersing lens separated by an air space having a negative effect. The second group consists of a cemented negative and a positive lens, the cemented surface having a positive effect.

In the early unsymmetrical Protar lens, the opposite effects by which astigmatic correction is secured are derived solely from the action of the cemented surfaces. In the Unar, the correction is obtained from the opposite powers of the two pairs of facing surfaces. In the Tessar, these opposite astigmatic effects are obtained by giving to the power of the cemented surface the opposite sign to that presented by the facing surfaces of the other group of lenses.

This design has been one of the most successful of all for large aperture anastigmatic objectives and has been widely copied for lenses with relative apertures ranging from f :4.5 to f :3.5 and, in some cases, to f :2.7.

Among well known objectives of this type are: Aldis, *Series 1; Kodak Anastigmat f:4.5* and *Ektar* f :3.5 Krauss *Trianar,* f :4.5 Dallmeyer *Serrac* (B.P. 27,518 of 1912) and *Dalmac* f: 3.5; Schneider *Xenar* f :4.5 and f :3.5; and the Wollensak *Velostigmat Series II,* f :4.5.

A modification of this principle which consists in the use of a rear component of three-glasses instead of two is represented by the Ross *Xpres* (Fig. 94) made in 3 series, f :4.5, f :3.5, f :2.9 and the Gundlach *Radiar* (Fig. 95). In each case, the three glass element was adopted because it allows a different selection of glasses and affords greater latitude in balancing the opposing powers of component parts of the system.

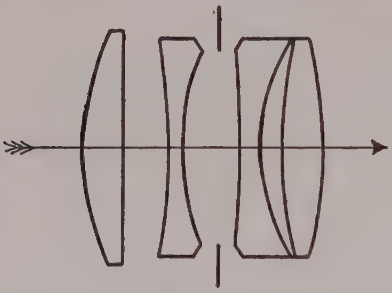

FIG. 94. Xpress of Ross

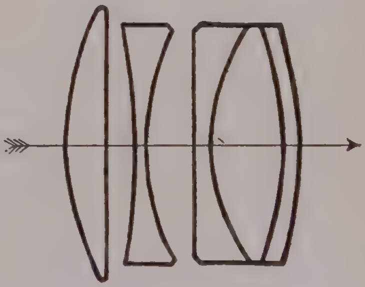

FIG. 95. Radiar of Gundlach

A triplet construction in which both the front and rear elements are cemented doublets (Fig. 96) has been patented by Booth (B.P. 151,506).

This objective, which was issued commercially by Dallmeyer (London) as the *Pentac,* is similar in appearance to the Heliar but is a development of the triplet, with rear cemented surface. The substitution of a cemented doublet for the single front lens by increasing the number of elements at the disposal of the calculator, makes possible an exceptionally well corrected objective with an aperture of f :2.9.

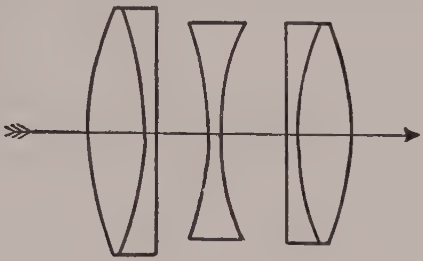

FIG. 96. Pentac of Dallmeyer

Photographic Objectives Developed from the Gauss Telescope Objective.—Objectives of this construction are based upon the Gauss telescope which in its simplest form consists of two meniscus lenses separated from one another by an air space and having their concave sides facing the incident light.

This design is noteworthy for the large, flat field and excellent corrections, except for coma, obtainable at a large aperture. Satisfactory comatic correction can be secured, however, by departing from a strictly symmetrical construction.

Objectives of this type may be divided into three classes: (1) the older lenses, (2) modern large aperture lenses, and (3) rapid wide angle lenses.

The Planar.—In 1896, Paul Rudolph calculated for Carl Zeiss of Jena an objective along the lines of the Gauss construction, which was placed upon the market as the *Planar* (Fig. 97). The Planar differs from the essential form of the Gauss construction as shown in Fig. 98 by the replacement of the inner menisci by two cemented lenses.

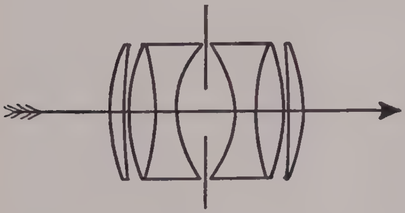

FIG. 97. Planar of Rudolph

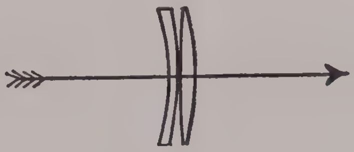

FIG. 98. Gauss Objective

These two lenses are made of glasses having identical refractive index but different dispersions. Therefore, the inner cemented lenses act as a single lens so far as the refractions of any single color are concerned, while, owing to the difference in the dispersive values of the two glasses, the amount of chromatic aberration may be altered simply by changing the curves of the two cemented surfaces which separate the two mediums of different dispersion. In this way, the chromatic aberration of the two cemented lenses may be made to equalize the chromatic aberration of the two outer lenses so that satisfactory color correction may be obtained at the same time that the astigmatic and spherical errors are corrected. The relative aperture of the Planar is f :3.5, but owing to the presence of considerable coma the definition at this aperture is not critical and stopping down is necessary for critically sharp definition. The Planar is no longer made, having been replaced by the unsymmetrical anastigmats which have approximately equal speed and superior correction.

Later, it was found possible through choice of suitable glasses to produce an objective corrected for the usual errors, except coma, with only two lenses, thus retaining the essential form of the Gaussian design. Kollmorgen's method was to make each combination of an anomalous glass pair; i.e. the coefficient of refraction of the collecting lens with low dispersion must be as large or larger than the dispersing lens. The best known lenses of this type are the *Aristostigmat* of Hugo Meyer, the *Homocentric* of Ross, the *Omnar* of Busch and the *Double Orthar* of Plaubel. In some of these the comatic correction has been improved by departing from strictly symmetrical construction.

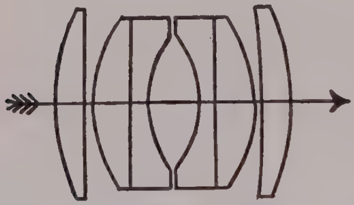
FIG. 99a. Opic of Cooke

The Cooke *Opic* (Fig. 99) has an aperture of f :2 and consists of six lenses symmetrically arranged, but in reality is an unsymmetrical construction since the portions on either side of the diaphragm are not identical. The angle of view is approximately 45°.

The Kodak *Ektar* f :2, the Schneider *Xenon* f :2, the Ross *Xpress* f :1.9 (B.P. 323,138 of 1929) and the Zeiss *Biotar* f :2 are similar. The first two cover an angle of approximately 45°. The Biotar covers an angle of 55° and is used as a medium wide angle lens on the Zeiss Contax.

A modification of this construction designed by Lee of Taylor, Taylor and Hobson for kinematography and miniature camera use is completely unsymmetrical in design and covers an angle of 35° at a relative aperture of f:2. The field has been purposely reduced in order to secure more perfect correction at the large aperture.[6a]

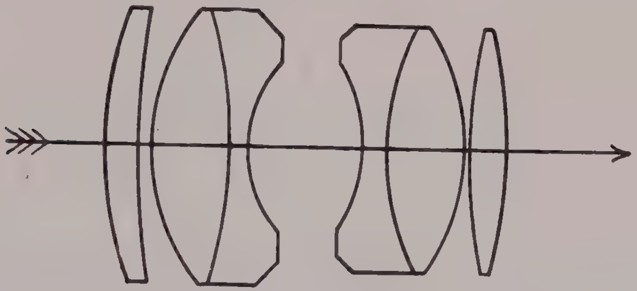

FIG. 99b. Gaussian Construction F:2 of Cooke

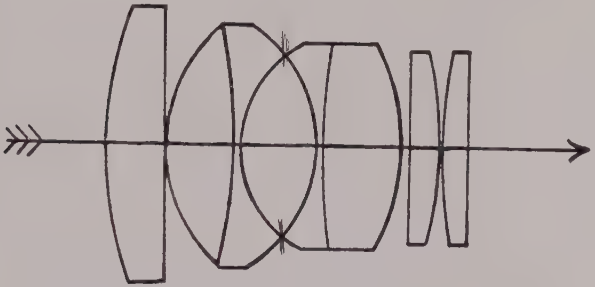

FIG. 99c. Gaussian Construction F:1.4 of Cooke

A further development in which deeper curves are employed and the rear converging element divided into two of lower power was patented the same year.[6b] This includes an angle of approximately 50°, has a relative aperture of f:1.4 and is designed for miniature cameras.

A number of wide angle lenses are based upon the Gauss constructions. Among them, the Cooke Series VIIb (Fig. 100) which covers an angle of 90° at f:16 and 100° at f:32, the Wollensak Series III f:9.5 (Fig. 101) which covers an angle of 90°, the Dallmeyer wide

[6a] B.P. 377,537 of 1932.

[6b] B.P. 373,950 of 1932.

LEE—The Taylor, Taylor and Hobson F/2 Anastigmat. Trans. Opt. Soc., 25 (1924), 240.

angle f:11 (Fig. 102) and the Meyer Wide Angle f:9 covering an angle of 100°.

The construction shown in Fig. 103 is similar to the Planar of Rudolph except that the two meniscus lenses are placed on the inside next to the diaphragm. This design is especially favorable for the elimination, at a relatively large aperture, of the errors arising from chromatic difference of spherical aberration and for the large, flat field. A symmetrical objective of this type having a relative aperture

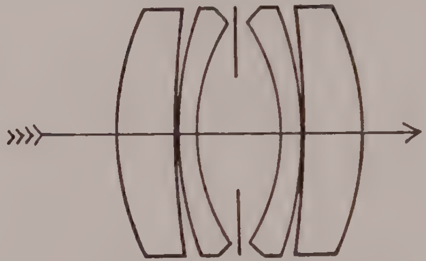

FIG. 100. Cooke Series VIIb (Wide Angle)

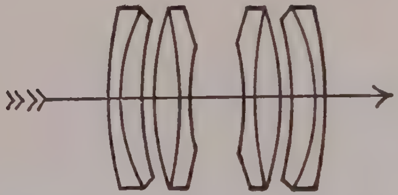

FIG. 101. Wollensak Velostigmat, Series III, Wide Angle F/9.5

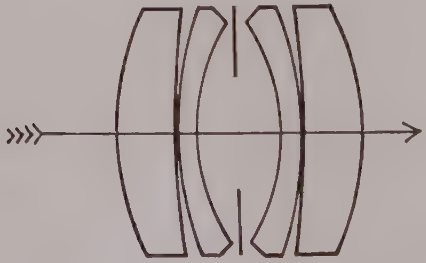

FIG. 102. Dallmeyer Wide Angle F/11

of f:6 for the combined lens and an aperture of f:11 for the single lenses, has been made for several years by Hugo Meyer and **Co.** of Goerlitz (Germany) as the *Euryplan.*[7]

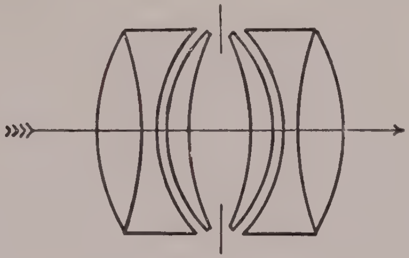

Fig. 103

The *Plasmat* calculated by Paul Rudolph and issued commercially by Hugo Meyer, of Goerlitz, is the first anastigmatic objective in which an attempt has been made to secure greater depth and plasticity on planes before and behind the plane in sharp focus. Previously, it was the aim of designers of photographic objectives to secure the best possible reproduction of an object occupying a single plane; i.e. the conditions existing in copying. According to Rudolph, the construction adopted for the Plasmat has made possible a higher degree of spherical correction for the different colors, thus producing an image with greater depth and plasticity than other photographic objectives.[8]

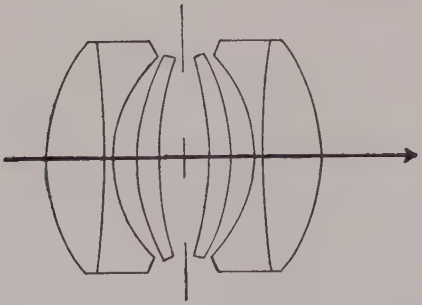

Fig. 104. The Plasmat of Rudolph (Convertible)

The first Plasmat was introduced as a symmetrical objective (Fig. 104), the complete lens having an aperture of f:4 and the single elements an aperture of f:8. This was followed several years later by an unsymmetrical construction (Fig. 105) having an aperture of f:2.9 (angle 75°) known as the *Mikro-Plasmat,* and a series known as the *Kino-Plasmat* (Fig. 106) having an aperture of f:1.5 designed particularly for motion picture use and miniature cameras.

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[7] Patented by E. Arbeit, 1901.

[8] It has been stated (Zschokke) that the plasticity in the rendering of planes at different distances from the camera is due to the presence of a small amount of uncorrected chromatic aberration. *Phot. Ind.,* 1921, p. 257.

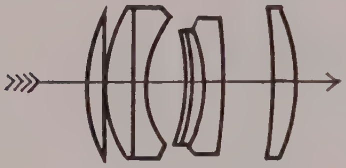

FIG. 105. Mikroplasmat

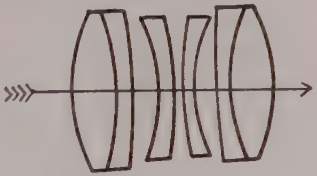

FIG. 106

The Ross *Wide Angle Xpress* (Fig. 107) was designed for aerial survey and has a relative aperture of f:4 covering an angle of 70° at full aperture; an objective of 7 inches focal length is used on a 7 × 7 plate. It is of unsymmetrical design and is so well corrected that it may be used for infrared photography without refocusing.

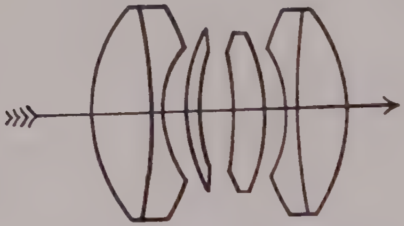

FIG. 107. Ross Wide Angle X-press

A development of the Gauss lens designed by Lee of Taylor, Taylor and Hobson for use in aerial surveying is shown in Fig. 108. This includes an angle of approximately 70°—an objective of 5 inches focal length covers sharply a 7 × 7 inch picture—at a relative aperture of f:4.5. Of the four separated components only one (the second) is dispersive, the rear component being either collective or, in some cases, of zero power. In the usual lens of this type, the order is alternatively

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RUDOLPH—Rendering of Space in Photographs. Kinotech., **8** (1926), 179–183.

RUDOLPH—Spatial Delineation and Zone Free Spherical Correction. Kinotech., **11** (1929), 339–341.

collective and dispersive, dispersive and collective. The change results in a larger flat field and improved general correction.[8a]

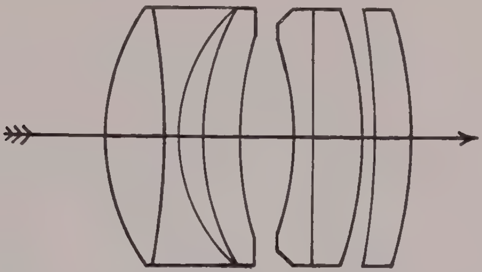

FIG. 108. Construction for Aerial Photography by Taylor, Taylor and Hobson (London)

Unsymmetrical Constructions Consisting of an Old and New Achromat Separated by the Diaphragm.—Paul Rudolph of the Carl Zeiss Werkstaette at Jena was one of the first to take advantage of the newer glasses introduced by the Jena Glass Works in the construction of photographic lenses. The first of Rudolph's anastigmatic objectives with which we are concerned was introduced in 1890 under the name Protar. This objective (Fig. 109) consisted of two glass pairs, one being the old normal glass pair made from the old glasses, the other the abnormal glass pair made from the newer varieties of Jena glass. One of the combinations has a positive astigmatic difference: i.e., the focal length of the rays in the primary section is greater than in the secondary section; while the other combination has a negative astigmatic difference, the focal length of the rays in the primary section being less than in the secondary section. By proper construction, the two opposite effects may be so balanced as to compensate one another so that there is no sensible astigmatic difference when the complete objective is said to be an anastigmat.

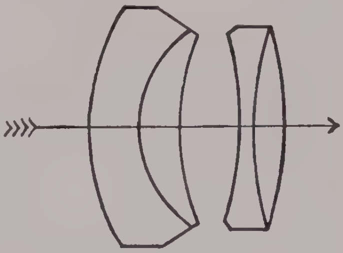

FIG. 109. Rudolph's Protar (1890)

In the normal glass pair, the refractive index of the positive lens is lower than the adjacent negative lens, while in the abnormal glass pair, the positive lens is of higher refractive index than the negative. Both components are separately achromatized, but are not necessarily of the same focal power, as one component may be strongly positive while the other may act simply as a corrective system for the whole. This construction, because of its relatively small aperture, is no longer made except for wide-angle objectives where its extensive field makes it very suitable.

[8a] B.P. 407,156 of 1934.

Among wide-angle lenses of this type are: the Zeiss Protar Series f:18; the Bausch & Lomb Medium Wide Angle Series IV f:12.5, and Extreme Wide Angle Series V f:18; the Schneider Daskykar f:12.5 which covers an angle of approximately 100°.

The Anastigmatic Triplet of H. D. Taylor and its Derivatives.—The first anastigmatic triplet was designed by H. Dennis Taylor in 1895 and is generally known as the Cooke triplet since Mr. Taylor was then in the employ of T. Cooke & Sons Ltd.

In this triplet construction (Fig. 110) the two outer collecting lenses are identical and are designed to be practically free from coma; this result is secured by the use of an intermediate form of lens in which the inward coma of one surface is neutralized by the outward coma of the opposite surface. The burden of correcting the entire system is thrown upon the central dispersing lens, which fulfills a threefold office: (1) It flattens the final image and corrects marginal astigmatism, producing a flat astigmatic field; (2) it corrects the color aberrations of the convergent lenses and makes the complete system achromatic; (3) it corrects the residual spherical aberration of the two collecting lenses and renders the final image aplanatic. The action of the negative lens in securing a flat field, free from astigmatism, may be explained with the aid of Fig. 111. *L* and *N* are respectively positive and negative lenses of equal focus and of the same materials. With primary sections of the oblique pencils, the image formed by the positive lens, *L*, is curved spherically, *p-P*, but the interposition

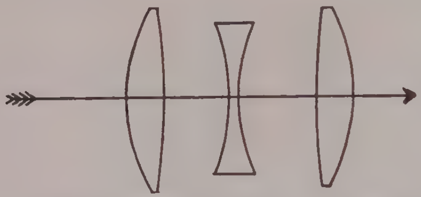

FIG. 110. Triplet Anastigmat of H. D. Taylor (Cooke)

of the negative lens, N, throws back the image to the plane Q-Q' which is flat because the curvature errors of the positive lens, L, are exactly neutralized by the opposite curvature of the negative lens, N.

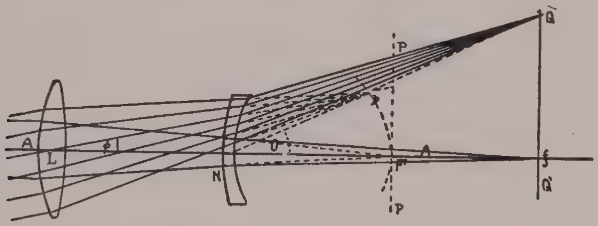

FIG. 111. Action of the Central Diverging Lens of the Cooke Triplet Anastigmatic Objective

Owing to the fact that this arrangement would result in considerable distortion, and to the fact that its corrections to a certain extent depend upon the distance of the subject, the single collecting lens is divided into two which are alike in power and shape but turned in opposite directions. The positive focal power of the two converging lenses is approximately equal to the negative focal power of the central dispersing lens.[9]

Because of its simple construction and excellent performance, the triplet design is widely employed by manufacturers of photographic lenses. Among well known triplet constructions may be mentioned: Zeiss, *Triotar* f:3 and f:3.5, Meyer *Trioplan* f:3, Steinheil *Cassar* f:4.5 and f:3.5, Schneider *Radionar* f:6.3 and *Kinoplan,* Leitz *Hektor.*

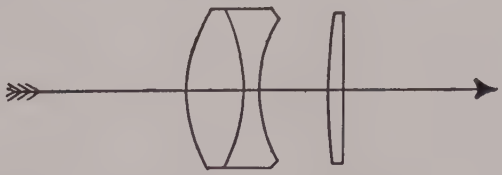

FIG. 112. Modification of the Anastigmatic Triplet

A simplification of the original triplet design by H. L. Aldis consists (Fig. 112) of a cemented combination of a positive and a negative lens in front of the diaphragm and a single positive lens in the rear.

In this design, the spherical corrections are made principally by the cemented surface of the front component and the astigmatic corrections by the rear element. This design is well adapted to objectives intended for hand camera use having a relative aperture of f :6.3, f :7.7 or smaller.

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[9] A modification of the original triplet involving shallower curves to reduce cost of manufacture has been patented by Warmisham. B.P. 157,036 of 1920.

A second development of the original simple triplet of H. D. Taylor consists (Fig. 113) of two positive elements, each a cemented doublet, with a centrally placed negative component. The increase in the number of elements of construction and the introduction of cemented surfaces enable the necessary corrections to be carried out more easily and completely than in the simple triplet and results in an objective with better correction and covering a larger field.

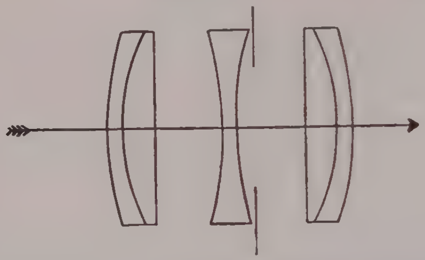

FIG. 113. Modification of the Anastigmatic Triplet (Heliar)

Both symmetrical and unsymmetrical objectives of this type have been designed. The unsymmetrical design permits more complete correction for astigmatism and curvature of field, but is not perfectly rectilinear.

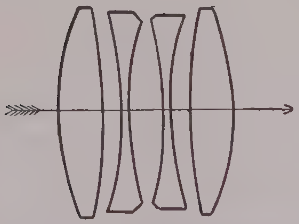

FIG. 114. Modification of the Anastigmatic Triplet (Warmisham's Aviar).

The best known objective of this type is the *Heliar* of Voightländer. The *Dynar*, a similar objective of smaller aperture (f :6.8), also by Voightländer, is no longer made.

A third modification of the simple triplet consists essentially in dividing the central negative lens into two similar lenses but of lower individual power. This permits the employment of shallower curves than the single negative lens of the original triplet, and enables the corrections for coma to be carried out more thoroughly resulting in a larger flat field. The best known objective of this type is the *Aviar* of Taylor, Taylor and Hobson which was designed by Warmisham.[10]

[10] B.P. 113,590 of 1918 and B.P. 312,536 of 1929.

Unofocal.—In 1901, Steinheil introduced as the *Unofocal* an anastigmatically corrected objective similar in appearance to the design just discussed but based upon an entirely different principle. In the Unofocal, all four lenses are made of glass of practically the same refractive index. Achromatism is secured by a suitable adjustment of the separation between the elements and, while there is neither an abnormal nor normal glass pair, the conditions necessary for spherical and astigmatic correction are satisfied. Spherical correction is obtained by two refractions in the same direction, and astigmatic correction by the two glass-to-air surfaces, which constitute convex and concave surfaces facing a medium of higher refractive index.

The Unofocal is made by Steinheil in several series, the most rapid with a relative aperture of f :4.5. Among other lenses based upon the same construction are the Gundlach Anastigmat f :6.3, the Kodak Anastigmat f :7.7 and the Graf Anastigmat. Some of these are symmetrical.

Two other unsymmetrical objectives based upon the same principle may be mentioned, the *Isostigmar* and *Neostigmar* of Beck (London). These, however, unlike the Steinheil Unofocal, do not obey the Petzval condition. The Neostigmar is also convertible; removing either the third or fourth lens provides three different focal lengths in the same objective.

Teleobjectives.—There are two kinds of teleobjectives, one composed of a positive combination, constituting a separately corrected objective, and a negative combination corrected for spherical and chromatic aberration (compound teleobjective), and the other a positive and negative combination which are not individually corrected, the aberrations of the positive component being brought to a minimum by making those of the negative component of the opposite character and as nearly equal as possible (fixed magnification teleobjective).

It is difficult to obtain a large working aperture with the compound teleobjective so, despite the advantage of variable magnification, this type of objective has practically disappeared from the market. Most manufacturers, however, will construct telephoto attachments to order for such of their objectives as may be suitable. The fixed magnification teleobjective has the advantage of producing, with approximately

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Beck—A New Principle in Photographic Lens Construction. Phot. J., **44** (1904), 172.

Lee—Principles and Construction of the Telephotographic Lens. Phot. J., **65** (1925), 392.

the same camera extension, an image from two to three times as large as the usual camera lens (the magnification varies in different lenses) and its large relative aperture (f :5.5 or larger) enables it to be used for rapidly moving objects, sporting events, etc.

The first of the modern fixed magnification teleobjectives was calculated by Martin and introduced by Emil Busch[11] of Rathenow (Germany) in 1905 as the *Bis-Telar* (Fig. 115). This teleobjective had a relative aperture of f :9 and a magnification of 1.65. Teleobjectives of similar design but with greatly improved correction and larger relative apertures have been introduced in recent years. Prominent among these are the *Large Adon* and *Dallon* of Dallmeyer (London), the *Telic* of Taylor, Taylor & Hobson, Leicester (England) and the *Radiar* of Gundlach (Fairport, N. Y.). The first mentioned, calculated by Lan-Davis,[12] has a relative aperture of f :4.5 while the second, calculated by Booth, is made in several series[13] with relative apertures ranging from f :5.6 to f :8. The magnification in all cases is approximately two times. The Cooke *Telic,* calculated by Lee,[14] has a relative aperture of f :5.5 and a magnification of two times.

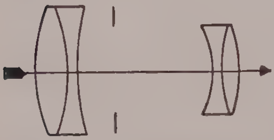
FIG. 115. Bis-Telar of Busch

The Tele-tessar of Zeiss[15] and the *Telegor* of Goerz differ from the teleobjectives described in the form given the rear component which consists of a pair of cemented meniscus lenses, the positive member being placed nearest the diaphragm and not on the outside (Fig. 116). These objectives have a relative aperture of f :5.5 and a magnification of two times.

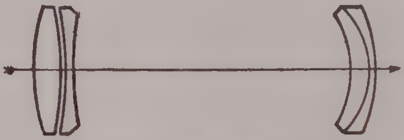
FIG. 116. Tele-tessar of Zeiss

The *Teleros* of Ross Limited (London) is made in two series: one having a relative aperture of f:5.5 and a magnification of two times, the other a relative aperture of f:6.3 and a magnification of three times. In both cases, the rear component is a cemented triplet (Fig. 117).[16]

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[11] B.P. 15,372.

[12] B.P. 1185 of 1914.

[13] B.P. 139,719 and 151,507 of 1920.

[14] B.P. 198,958.

[15] B.P. 179,529, U.S.P. 1,467,804.

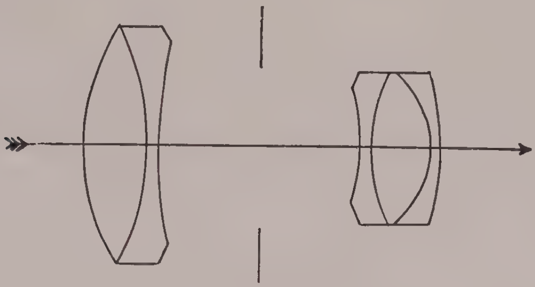

FIG. 117. Teleros of Ross Ltd.

A similar objective in which the rear component is a cemented triplet, is made by Taylor, Taylor and Hobson of Leicester (England). This was calculated by Lee and has an aperture of f:5.5 and a magnification of three times.[17]

Types of Lenses Used for Portrait Work.—Four types of lenses are in general use for portrait work:

1. Lenses of the Petzval construction.
2. The anastigmat.
3. The diffused-focus lens.
4. Triplet constructions.

The portrait lens, owing to its curved field, is used today chiefly for head and shoulder portraits. For this purpose it is, however, favored by many portrait workers because of the plastic quality of the image.

Anastigmats working at a relative aperture of f:4.5, or larger, are used quite extensively for portrait work particularly for groups and for full and three-quarter figures. The critical definition of lenses of this type is not required in portrait work and in head and shoulder portraits especially may be objectionable since most sitters, unlike Cromwell, do not want every wart and pimple to show. A number of manufacturers therefore provide lenses of the focal lengths commonly employed for portrait work with a means of softening the definition by introducing a certain amount of spherical aberration through alteration of the position of one of the elements of the lens. The biting definition of lenses not provided with such an adjustment may be softened by using diffusion disks over the lens or by covering it with one or more thicknesses of black chiffon. Cutting a small opening in the cloth will make the definition somewhat sharper than when the entire lens is covered.

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[16] B.P. 188,621.

[17] B.P. 132,067.

The diffused-focus lens is preferred by many portrait photographers because it subdues detail, accentuates the feeling of atmosphere about the subject, and the negatives require less retouching. The degree of diffusion is usually controlled by the size of the diaphragm. Diffused-focus lenses require more than ordinary care in focusing and in the lighting of the subject if objectional halos are to be avoided.

For head and shoulder portraits particularly, a lens of relatively long focal length is desirable. A good rule to follow is this: Use a lens whose equivalent focal length is at least twice as great as the diagonal of the photograph. For full-length figures and groups, a lens of shorter focal length may be used as the subject-to-camera distance is greater. A lens having a focal length from 50 per cent to 60 per cent greater than the diagonal of the photograph may be regarded as the minimum.

An important factor in the choice of the focal length of the lens is the size of the studio. To determine the length of the studio required for a lens of any given focal length, regard the average head as being nine inches in height and the standing figure as eight feet. Calculate the degree of reduction for the size of image desired and multiply the degree of reduction by the focal length of the lens and add one focal length. The result is the lens to subject distance. It is usual to add five feet to this distance to allow for the camera and background. For example, if the focal length of the lens is 20 inches and it is desired to make a head two inches high, the degree of reduction is 1/4.5 and the lens subject distance is 110 inches (4.5 times 20 plus 20 equal 110). Adding to this 60 inches (5 feet) we have a total of 170 inches or 14 feet 2 inches which is the working space necessary.

Lenses for Commercial Photography.—Anastigmat lenses of the symmetrical type whose single element consists of either three or four cemented lenses, are deservedly popular among commercial photographers due to the excellent definition of good lenses of this type, the relatively large field and to the fact that such lenses afford a choice of at least two, and frequently three, focal lengths by using the elements singly. While not as rapid as many anastigmat lenses of unsymmetrical construction, they are sufficiently rapid for most of the requirements of commercial photography.

For general exterior work the focal length of the complete lens should be equal to, or slightly less than the diagonal of the picture. A focal length approximately twice that of the complete lens will then be obtained by using the single element, if both elements are the same focal length. If the focal lengths of the two elements are unequal, one is usually somewhat *less,* and the other slightly *more,* than *twice* the focal length of the complete lens.

The single lens should always be used behind the diaphragm regardless of its position in the complete lens. Shutters designed for use with convertible lenses usually have three diaphragm scales, one for the complete lens and one for each element when used alone. The scales are marked with the focal length of the lens, or " B " and " F " which refer to the back or front half of the lens.

Anastigmat lenses of the unsymmetrical type are employed by many photographers and are satisfactory except where convertibility is desirable. When such lenses are preferred the most rapid series should not be chosen for work demanding the utmost sharpness. In this case, the less rapid series should be chosen on account of its superior correction and the reserve covering power, which is greater than that of the more rapid lenses even when the latter are used at a smaller stop. With a lens of this type, it is desirable that the focal length be slightly greater than the diagonal of the picture in order that the covering power of the lens be sufficient to permit the free and complete use of the camera swings.

Wide Angle Lenses.—A number of anastigmat lenses of symmetrical construction, particularly those of the cemented type, when stopped down will cover a larger plate than that for which they are intended and so may be used as a wide angle lens where neither speed nor an extremely wide angle is required. Some medium speed lenses of unsymmetrical construction will also cover a larger plate when stopped down, but, generally speaking, the increase in the size of the field upon stopping down is much less than with lenses of symmetrical construction, so that, with a very few exceptions, lenses of this type will not serve as wide angle lenses when stopped down.

Wide angle lenses, properly speaking, may be divided broadly into two types, namely *medium* and *extreme* wide angle. Lenses of the first class are usually designed to work at a larger aperture and are, for the most part, based upon the Gaussian construction. This construction is especially favorable towards a large field at a relatively large aperture. Lenses of this type may have an aperture as large as f :9.5, and cover an angle of 90 degrees. The Wollensak Velostigmat, Series III f :9.5, the Meyer Wide Angle f :8, the Dallmeyer Wide Angle f :11, to mention only three, are of this general type. The Dallmeyer wide angle and the Cooke Anglic may be opened up to f :6.5 for focusing but must be used at f :16. The larger opening facilitates focusing in dark places.

Most extreme wide-angle anastigmatic lenses are unsymmetrical constructions consisting of two cemented lenses on either side of the diaphragm. (See page 125.) This type of lens can be made to cover sharply a very wide angle but cannot be made to work at a large aperture, its usual working aperture being from f :16 to f :18. As there are no air spaces, and only four reflecting surfaces, it is largely free from internal reflections and is well adapted for use with subjects containing naked lights, such as street lights, electric signs, chandeliers, etc. The Zeiss *Protar* Series V, f :18, the Bausch & Lomb *Extreme Wide Angle Protar* and many others are of this type.

The Hypergon.—This extreme wide angle lens was designed by E. Von Hoegh in 1900 and covers an angle of approximately 135°. It consists of two thin hemispherical lenses symmetrically placed about a central diaphragm (Fig. 118). It is uncorrected for chromatic or spherical aberration but, in consequence of the radii of the surfaces being nearly the same, it possesses an anastigmatic flat field.

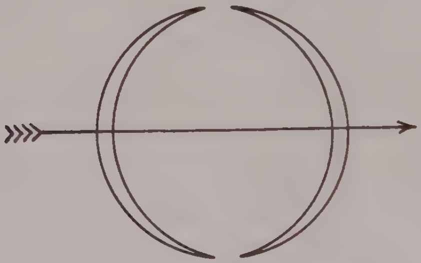

FIG. 118. Goerz Hypergon

To secure even illumination over its large field, an opaque star-shaped diaphragm is mounted directly in front of the lens. This is revolved during the exposure, thus reducing the illumination in the center of the field. A small diaphragm must be used in consequence of the large amount of uncorrected spherical and chromatic aberration and the actual working aperture is about f:40.

Lenses for Aerial Photography.—Lenses designed for aerial photography must have critical definition over a large flat field, must be free from distortion, the illumination of the image must be as nearly uniform, and the relative aperture as large as possible. A relatively wide angle is desirable, if obtainable without the sacrifice of the foregoing essentials. Objectives specially designed and constructed for aerial photography are employed for all mapping and survey work in which the utmost precision is necessary.

Lenses for Reproduction Processes.—The objective used for copying and process work should give critical definition and even illumination over the entire film, should be free from distortion and, for color reproductions, *apochromatic,* i.e., chromatically corrected for three colors instead of two. These conditions can be satisfactorily met in the present state of photographic optics only through the use of objectives having a relatively long focal length in relation to the size of film or plate which they are designed to cover and a comparatively small aperture, f:10 or smaller.

Lenses of this type are designed for use at or near unit magnification, and differ in this respect from other photographic objectives which are designed for use with objects at a greater distance from the lens. Process lenses are favored in certain quarters for commercial photography in the studio where still-life subjects demanding critical definition are involved as well as for three-color photography.

CHAPTER V

THE PHOTOGRAPHIC EMULSION

Introduction.—A photographic emulsion is not a true emulsion but a suspension of a light sensitive solid in a colloid. While light-sensitive emulsions may be prepared from the salts of several metals including mercury and thallium,[1] only those of silver halide are of practical importance. Albumin (1847) was the first colloid used in photographic emulsions; this was followed by collodion in 1851 which, in turn, was superseded by gelatin (1872). Although attempts have been made to use agar and casein, mainly in emulsions for printing papers, only gelatin is of practical importance.

In making an emulsion a solution of silver nitrate is added to a solution of gelatin containing an alkaline halide, the reaction in the case of silver bromide being $AgNO_3 + KBr = AgBr + KNO_3$. The gelatin is first allowed to swell in cold water and then dissolved by heat, after which the alkaline halide (either bromide, chloride or iodide) is added and finally silver nitrate.

The precipitation or "emulsification" of the silver halide in gelatin is a very critical operation; the particles must be of the proper size and evenly distributed throughout the gelatin solution. To increase the sensitivity, emulsions intended for use in the camera are subjected to a process known technically as ripening which is accomplished by heating the emulsion or by the addition of ammonia. After ripening, the emulsion is washed to remove the alkali nitrate (KNO_3) and other soluble substances.

Both of these operations are frequently omitted in the case of the less sensitive and more dilute emulsions employed for contact printing papers.

The emulsions for films and plates intended for use in the camera consist of nearly pure silver bromide or silver bromide and a small

[1] Luppo-Cramer, *Die Grundlagen der Photographischen und Negativ-Verfahren.*

Carroll—A Summary of Emulsion Knowledge. Brit. J. Phot., **79** (1932), 622, 637, 654, 684.

Renwick—The Manufacture of Sensitive Emulsions as a Science and an Art. J. Soc. Chem. Ind., **42** (1923), 43.

amount of soluble iodide, while the less sensitive emulsions used for papers consist of pure silver bromide (bromide papers) silver bromide and silver chloride (chloro-bromide papers) or silver chloride (developing out or gaslight papers) the order of sensitiveness decreasing generally in this order.

In negative emulsions, the silver halide forms from 30 to 40 per cent of the total weight of the dry emulsion. The proportion is usually much less in emulsions for printing papers.

While the formulas and manufacturing procedures employed in the preparation of commercial emulsions are closely guarded trade secrets, the general principles are well known and will be discussed in the following pages.

Gelatin.—If silver halide is formed in an aqueous solution by the double decomposition of a soluble halide, such as potassium bromide and silver nitrate, and the solution allowed to stand a short while, the silver halide will begin to precipitate upon the sides and bottom of the vessel. However, if the silver halide is formed in the presence of a colloid, such as gelatin, the solution, at first clear and slightly opalescent, becomes creamy or milky on standing and the silver halide does not precipitate out of solution but remains uniformly distributed in the solution. The colloid (gelatin) thus acts as an emulsifying medium, or vehicle, holding the particles of silver halide in suspension.

As a vehicle, gelatin is immensely superior to any other colloid. Of primary importance from the standpoint of photographic emulsions is the easy reversibility of the transition from the hydrosol to the hydrogel at readily attainable temperatures. As a hydrosol, it renders possible the formation of a suspension of silver halide particles in a

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Fuchs—Testing Gelatins for Emulsions. Phot. Ind., **31** (1933), 254. S.&I.P. (II), **4** (1933), 160.

Sheppard—Effect of Concentration of Sensitizer on Speed, and Fog Corrections. Phot. J., **66** (1926), 399–409.

Sheppard—Sulphur Compounds and Photographic Emulsions. S.&I.P. (II), **7** (1936), 361.

Sheppard—Photographic Gelatine. Phot. J., **65** (1925), 380.

Sheppard, Elliott and Sweet—Photographic Properties of Gelatine. Physical Chemistry of the Photographic Process. (Published as Transactions of the Faraday Society.)

Sheppard—The Modern Chemistry of Gelatine. Brit. J. Phot., **69** (1922), 677, 695, 706, 710; J. Ind. and Eng. Chem., **14** (1922), 1023.

Slater-Price—Gelatine. Phot. J., **62** (1922), 356.

Slade—Colloid Chemistry in Photography (Bibliography). Brit. J. Phot., **67** (1920), 645.

medium which can readily be spread on paper, film, or on glass plates, converted by chilling into a hydrogel, and upon drying forms a vehicle capable of holding the photosensitive silver halide permanently in position on the base and at the same time is of such a nature as to allow the free passage of the solutions in processing. Thus it is the properties of the hydrosol which are of importance in the preparation of the emulsion and those of the hydrogel which concern its behavior in use.

Aside from functioning as a vehicle, gelatin acts as a protective colloid. Silver halide formed by precipitation in an aqueous solution is immediately attacked and reduced to silver by a developer whether exposed to light or not. If, instead of water, the silver halide is formed in a solution of a colloid such as gelatin, the rate of reduction is greatly decreased, especially for silver halide which has not been exposed to light. The difference in the rate of reduction for exposed and unexposed silver halide, when precipitated in a colloid, renders development possible. Without the protective action afforded by a colloid all possibility of obtaining an image is eliminated as the silver halide, whether exposed or not, is immediately reduced by the developer.

The exact mechanism involved in the protective effect of a colloid is not clear. It is probably very similar to, if not identical with, the protective action observed in the case of gold and silver sols; however, in the case of photosensitive silver halide, there is the added difficulty of accounting for the difference in the rate of reduction for exposed and unexposed silver halide.[2] Apparently the chief function of a colloid in restraining reduction by developing agents is by retarding the deposition of silver either by raising the metastable limit by the exclusion of the nuclei or by hindering the coalescence of the silver amicrons.[3]

It has long been recognized that emulsions of higher sensitiveness may be prepared with gelatin than with any other colloid. Until only a few years ago it was a disputed point as to whether gelatin should be regarded as directly responsible or whether it acted merely as a passive medium which facilitated the production of large and more sensitive crystals.

It is now known that both viewpoints are correct and that ordinary commercial gelatin contains products which materially affect the sensitivity of the silver halide crystal. These were isolated by Sheppard and his coworkers in the Kodak Research laboratories and found to be allyl-isothiocyanate (mustard oil) and related sulphur-carbon compounds. The isothiocyanates are converted by ammonia into water-soluble thiocarbamides from which silver sulphide is formed as the result of a reaction, the nature of which is not yet clear.

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[2] Slater-Price, *Phot. Jl.*, 65 (1925), 94; Zsigmondy, *Kolloidchemie*, 1922; Freundlich, *Capillarchemie*, 1909.

[3] Sheppard, *Phot. Jl.*, 69 (1929), 330.

Many other substances have been found to act as sensitizers, but it is probable that in all cases the sensitizing action is due to the silver sulphide formed since allyl thiocarbamide does not act as a sensitizer except under conditions which result in the formation of sodium sulphide.

The formation of sodium sulphide is retarded by a low bromine-ion concentration or by acids; it is greatly accelerated by ammonia and alkalis generally.

Emulsions prepared with gelatin free of such sensitizing agents possess only moderate sensitiveness regardless of the manner of preparation. The addition of a small amount of any one of the sensitizing substances results in a marked increase in sensitivity which increases as the concentration of the sensitizer up to a point beyond which general fog is produced.[4]

The amount of the sensitizing substance necessary for optimum sensitiveness is very small; photographically active gelatin contains from 1 part in 300,000 to 1 part in 1,000,000 of the sensitizing substance sufficient to convert only a few molecules per 100,000 of silver bromide to silver sulphide.[5]

The mechanism involved in the increase in the sensitivity of the silver halide crystal by silver sulphide will be discussed later.

A gelatin, to be suitable for photographic purposes, must be free from mineral or other products which would cause decomposition, from organic sulphur and other reducing substances, as well as copper, lead, and iron. It must have a high viscosity, which must be retained when heated, a good jelly strength and setting power, and finally must be clear and free from color. These conditions are met only by the purest gelatin extracted at a relatively low temperature.[6]

The Three Classes of Emulsions.—Emulsions of silver halides in gelatin are conveniently divided into three classes:

1. Emulsions with an excess of silver nitrate. In this class are found all emulsions designed for printing-out. A typical example is gelatino-chloride printing-out-paper. With the virtual abandonment of printing-out-papers, this class of emulsions is of little importance.

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[4] Sheppard, *Phot. Jl.*, 66 (1926), 399.

[5] Sheppard, *Phot. Jl.*, 65 (1925), 380.

[6] See Sheppard, *Gelatin.*

2. *Emulsions with a considerable excess of soluble halide.* The best example of an emulsion of this character is the unwashed silver chloride emulsions employed for slow developing papers such as Velox, etc.

3. *Emulsions with a slight excess of soluble halide.* In this class belong all ordinary negative emulsions.

Emulsification.—The precipitation of the silver halide is a very important and exacting operation. The crystals of silver halide must be of the proper size and must not flocculate together and separate out but remain uniformly dispersed in the gelatin solution. The characteristics of the emulsion are very largely determined by the conditions existing during emulsification. This is particularly true of emulsions of low sensitivity and those designed for papers, in which the after processes of ripening or digestion are of little importance. In the case of negative emulsions, processes subsequent to emulsification may result in greatly increased sensitiveness, but it is not possible to convert a low speed emulsion of the positive type into one of high speed simply by digestion; an emulsion of high speed will be obtained only if the conditions of precipitation are favorable to the growth of silver halide grains of high sensitivity.

The conditions which affect the size of the crystals of silver halide formed upon precipitation and thus the photographic characteristics of the emulsion are (1) the concentration of the gelatin solution in

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Charriou and Valette—Researches on Silver Chloride Emulsions. Proc. Ninth Int. Congress of Phot., Paris. 1935. S.&I.P. (II), **6** (1935), 251.

Charriou and Valette—Positive Photographic Emulsions. Phot. J., **76** (1936), 407–410.

Leroy—Preparation of Fine-Grain Plates. Brit. J. Phot., **77** (1930), 125.

Prileshaeff—Preparation of a Bromide Paper Emulsion. Phot. Korr. **68** (1932), 150–152. S.&I.P., **3** (1932), 374.

Renwick—Note on the Factors Affecting Grain Size in Photographic Emulsions. Phot. J., **64** (1924), 324.

Steigmann—A High-Contrast Ammonia-Type Emulsion Rich in Silver Bromide. Phot. Korr., **71** (1935), 165.

Steigmann—Extra-Contrasty Positive Ammoniacal Gelatinobromide Emulsion. Phot. Korr., **71** (1935), 156. S.&I.P. (II), **7** (1936), 36.

Steigman—Green and Brown Developing Emulsions. Phot. Ind., **34** (1936), 764–766.

which the precipitation of the silver halide occurs; (2) the concentration of alkaline halide during precipitation; (3) the rate of addition; (4) the temperature and (5) the presence of ammonia or ammoniacal silver oxide. Quantitative data are lacking on all of these factors. Such data as may be available are known only to emulsion-makers and only general statements are to be found in recent literature on the subject of emulsions.

Curves published by Sheppard[7] indicate a definite relationship between the concentration of the gelatin solution in which the silver halide is precipitated and the average size of the grain. It is well known that only a part of the gelatin is present during emulsification and that in the case of high-speed negative emulsions the concentration of the reactants is higher and that of the gelatin lower than in low-speed emulsions. The grain size is affected also by the physical properties of the gelatin but again quantitative data are lacking.

In emulsions designed for development, the amount of alkaline halide present during precipitation is invariably greater than is necessary to combine with the silver salt to form silver halide. The presence of excess soluble halide during precipitation is essential in the preparation of high speed negative emulsions. Silver bromide is more soluble in the solutions containing a soluble bromide and the increased solubility results in the formation of larger and more sensitive grains. An excess of soluble halide also has the effect of reducing the danger of fog in the preparation of highly sensitive emulsions.

The usual practice in emulsification is to add the silver salt to the alkaline halide in gelatin; however, in the preparation of emulsions employing silver chloride there is less danger of flocculation if the chloride solution is added to a gelatin-silver nitrate solution.[8] The reason for this is unknown.

In some of the formulas given in Wall's *Photographic Emulsions* the alkaline halide (potassium bromide) and silver nitrate are added to the gelatin at the same time, the former, of course, being in excess. Since in this case the concentration of bromide is more nearly constant than when the two are added separately, it would appear to tend towards a more uniform grain-size.

The favorable influence of ammonia on ripening was observed in 1879[9] by Monckhoven who called attention to the fact that an emulsion might be ripened by the addition of ammonia instead of heat. Ammonia may be added to the emulsion as ammoniacal silver oxide in the process of emulsification or at a later stage. The presence of ammonia during emulsification results in a change in the crystal habit of the precipitated silver halide; the thin plate-like crystals not only become thicker and more rounded but tend [10] to clump together. Ammonia added to the emulsion after emulsification does not change the crystal habit of the grains already formed but does facilitate the ripening process. (See Ripening.)

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[7] *Brit. J. Phot.*, **69** (1922), 679.

[8] Eder, *Handbuch*, **III**, 5th Ed., 1903.

[9] *Phot. Korr.*, **16** (1879), 197.

Bromo-Iodide Emulsions.—The addition of iodide to gelatin-bromide emulsions was advised by Penney in 1878 and studied in detail by Abney and Eder. According to Abney [11] it is essential for high speed emulsions.[12] The use of iodide makes possible a higher degree of ripening and thus indirectly leads to emulsions of higher sensitivity. According to Carrol [12] the sensitivity of such emulsions is not realized unless they are ripened further. Although silver iodide is less soluble than silver bromide and would for this reason be precipitated first under ordinary conditions, Sheppard & Trivelli found no grains of silver iodide in a bromo-iodide emulsion.[13] Renwick & Sease found [14] that the larger grains contain more iodide. The x-ray diffraction studies by Wilsey show that the grains of a mixed bromo-iodide emulsion have the same type of lattice structure as those of silver bromide alone.[15] It appears, therefore, that the grains of the bromo-iodide emulsion may be looked upon as a mixture of silver bromide and iodide.

Huse and Muelendyke [16] found that the addition of iodide results

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[10] Carrol, "The Preparation of Photographic Emulsions," *J. Chem. Education*, **8** (No. 12, December, 1931), p. 2341.

[11] *Phot. News*, 1880, p. 174, 196.

[12] Carrol, *J. Chem. Ed.*, **8**, No. 12 (Dec., 1931), 2341.

[13] Sheppard & Trivelli, *The Silver Bromide Grain of Photographic Emulsions*. D. Van Nostrand, N. Y., 1921.

[14] *Phot. Jl.*, **64** (1924), 360.

[15] Wilsey, *J. Frank. Inst.*, **200** (1925), 739.

[16] *Phot. Jl.*, **66** (1926), 306.

BALDSIEFEN, SEASE AND RENWICK—Silver Iodide in Photographic Emulsions. Phot. J., **66** (1926), 163–184.

PRICE—Silver Iodide and Sensitivity. Phot. J., **75** (1935), 447.

STEIGMANN—The Silver Iodide Problem. Phot. Ind. (1929), 375–376.

TRIVELLI—Influence of Silver Iodide on the Sensitivity of Silver Bromide. J. Soc. Chem. Ind., **42** (1932), 908.

in a shift in the spectral sensitivity of the emulsion towards the longer wave lengths and it is reasonably certain that silver-bromo-iodide emulsions absorb more energy from white light than those of silver bromide alone. This alone, however, does not account for the increased sensitivity. In the opinion of Trivelli[17] the increased sensitivity is due to the strain set up by the presence of the silver iodide incorporated in the crystal structure of the silver bromide.

Ripening.—After emulsification, all emulsions except those for printing papers, are subjected to a process known technically as ripening, the purpose of which is to increase the sensitiveness to white light. Ripening is accomplished by keeping the emulsion at a relatively high temperature for a certain time, by the addition of ammonia, or both, although, when ammonia is added, the temperature must be lower if fog is to be avoided. Ripening results in a change in the number and size of the grains of silver halide present in the emulsion and in their composition. In the presence of a solvent such as free bromide, an increase in temperature causes the smaller grains to disappear and combine with the larger ones; although the number of grains present is thus reduced the average grain size is increased.[18] It was long supposed that the increase in sensitiveness produced in the ripening process was the result of the increased grain size, for it is well established that in general the large grains are more sensitive than the small. Sensitivity is not a function of grain size alone, however, and the increased size of the grains in the emulsion is a necessary but not a sufficient condition for high sensitivity.

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[17] *Rec. tran. Chem.* (4), **5** (1924), 360.

[18] Sheppard & Lambert, *Colloid Symposium Monograph,* **4** (1926), 281; **6** (1928), 265, Chemical Catalog Co., New York.

Carroll and Hubbard—Photographic Emulsion: Silver-Ion and Hydrogen-Ion Concentrations and Sensitivity. Bur. Stand. J. Res., **8** (1932), 481.

Lialikov, Piscounova, Chipilov, and Tcherdyncev. Digestion of Photographic Emulsions. Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 245.

Rawling and Glassett—The Sensitivity of Photographic Emulsions. I. The Effect of Changing Hydrion Concentration during the Washing and Digestion Stages. Phot. J., **66** (1926), 495–504.

Rawling—II Hydrion Concentration and the Silver Bromide-Thiocarbamide Complexes. Phot. J., **67** (1927), 42–48.

Tschibissof—Digestion of Photographic Emulsions. Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 248.

Coincident with the change in the size of the crystals of silver halide is a change in chemical constitution. One result of the ripening process is probably the reduction of a part of the silver halide to colloid silver.[19] The recent work of Sheppard on the sensitivity promoting substances in gelatin, while it does not exclude the possibility of the formation of colloid silver as one of the factors in ripening, indicates that an important, if not the primary factor, is the conversion of the allyl isothiocyanates, or other sensitizing substances present in gelatin, to thiocarbamide which, in turn, reacts with a portion of the silver bromide to form sensitivity centers, or nuclei, on the silver halide crystal. The way in which these centers of silver sulfide promote sensitivity is not entirely clear; the various theories which attempt to explain the mechanism involved will be discussed later.[20]

The function of ammonia in ripening is apparently closely connected with the formation of the sensitizing substances such as allylthiocarbamide described by Sheppard and Punnett.

Under given conditions of digestion the sensitiveness varies with the hydrogen-ion concentration. With a given emulsion the sensitiveness increases with increasing time of digestion to a maximum point which varies with the pH (or hydrogen-ion concentration).[21]

While it might be concluded that the change in sensitiveness with hydrogen-ion concentration is due to the amount of silver sulfide derived from the silver bromide-thiocarbamide reaction, this does not seem to be entirely the case, for it has been demonstrated that the sensitiveness of an emulsion, which is lowered upon the addition of acid, is immediately restored when the hydrogen-ion concentration is brought back to its original value.[22]

Eliminating the Soluble Salts.—After ripening, the emulsion is chilled and the gelatin sets to rather stiff gel. It is then shredded and washed in cold water to remove the alkaline nitrate formed in the precipitation of the silver halide and the excess halide and ammonia (when the last mentioned is used). The excess salts may be left in dilute silver chloride emulsions as used for contact printing papers, but other emulsions must be washed to prevent the salts from crystallizing out and also because they act as desensitizers.

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[19] Renwick, *J. Soc. Chem. Ind.*, 156T (1920), 39; *Brit. J. Phot.*, 67 (1920). 447, 463.

[20] See *The Silver Halide Grain of Photographic Emulsions.*

[21] Rawling and Glassett, *Phot. Jl.*, 66 (1926), 495.

[22] Rawling, *Phot. Jl.*, 67 (1927), 42. Sheppard and Wightman, *Phot. Jl.*, 69 (1929), 22.

The emulsion is placed in a press the bottom of which consists of a netting of silver wires. The pressure forces the jelly through the interstices of the wires breaking it up into fine shreds or "noodles" which are washed in cold running water. The quality of the water is a very important factor. It must be free of metallic or organic substances which would produce undesirable reactions. The alkalinity is also important. A moderately hard water is desirable as it tends to prevent the swelling of the gelatin. For this reason the temperature of the wash water must be kept relatively low, not above 10° C.

The ammonia and alkaline nitrate must be eliminated as completely as possible or the emulsion will possess poor keeping qualities. The soluble halide, on the other hand, must not be eliminated completely for experience has shown that the presence of a small amount has a favorable influence on the keeping qualities of the emulsion. Emulsions free of soluble halide develop fog in a relatively short time. The effect is more pronounced in the case of highly sensitive negative materials which by their very nature must be relatively unstable.

After-Ripening or Digestion.—At this stage, it is usual to add the remainder of the gelatin required for the completed emulsion, after which the emulsion may be again heated, usually at a lower temperature than before; a process known as after-ripening or digestion. This second heat treatment, unlike the first, has but little effect on the size of the silver grains but increases the sensitiveness and contrast of the emulsion. The increase in sensitiveness is very marked in the case of neutral emulsions and those containing iodide.[23]

The increased sensitiveness is apparently connected with the formation of the sensitivity centers, or nuclei, of silver sulfide. The formation of silver sulphide from thiocarbamide, and possibly from other sensitizing substances, is retarded by an excess of bromide. This tends to lend support to the theory that the reaction taking place during after-ripening or digestion is primarily one between the sensitizing substances and the silver halide producing sensitivity centers, or nuclei, of silver sulfide.

The rate of digestion increases with the hydrogen-ion concentration,

[23] Carrol & Hubbard, *Bur. Stand. J. Research,* 7 (1931), 219.

Carroll and Hubbard—The Photographic Emulsion: After-Ripening. Bur. Stand. J. Res., 7 (1931), 219–259.

Rawling—Effect of Thiocarbamide during After-Digestion. Proc. Ninth Int. Congress of Phot., Paris. 1935. S.&I.P. (II), 6 (1935), 247.

and for a given emulsion the sensitiveness varies with the time of digestion to a maximum which varies with the pH.[24]

Digestion must be carried out with great care in the case of high-speed negative emulsions in order to obtain high sensitiveness and the necessary contrast without fog.

Additions Prior to Coating.—If the emulsion is to be kept in storage for some time before coating, a preservative such as thymol, salicylic acid, or phenol is added to prevent bacterial growth which would cause decomposition of the gelatin. It is then chilled and placed in storage where it is kept at a relatively low temperature.

When required for coating it is first melted and certain substances, known as "doctors," are added to facilitate coating, or to harden the gelatin so that it will not become soft during the processing of the negative. Alcohol is added for the purpose of preventing the frothing of the emulsion in coating, glycerin, to make the emulsion coating pliable when dry, and saponin, to make the gelatin layer more receptive to the developing solution, while traces of chrome alum or formaldehyde are added to harden the gelatin and prevent frilling and softening.[25] Excessive hardening reduces contrast by retarding development. If chrome alum is used, there is the possibility of some loss in speed as it is sufficiently acid to reduce the pH value of the emulsion. The effect is not appreciable, however, with the amounts ordinarily used.[26]

The dyes necessary for rendering negative materials orthochromatic or panchromatic are also added at this stage.

Color Sensitizing.—Leading authorities in the field of photography generally agree that the expansion of the methods of optical sensitizing has been one of the most important factors in the advancement of photographic emulsion technique in the last decade.

Most of the work on the development of the actual sensitizers has been carried out in the laboratories of the photographic film manufacturing companies. Many of the patents granted both in this country and Europe are very brief and frequently contradictory. Thus, any one not directly and importantly connected with laboratories of the film companies is unable to write a complete treatise on the subject of dye sensitizing. This chapter is merely a brief resume of the subject as a whole.

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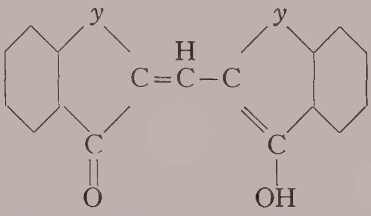
[24] Rawling & Glassett, *Phot. Jl.*, **66** (1926), 495; Rawling, *Phot. Jl.*, **67** (1927), 42; Sheppard & Wightman, *Phot. Jl.*, **69** (1929), 22.

[25] Baines, "The Manufacture of a Photographic Product." *Brit. J. Phot.*, **77** (1930), 780.

[26] "Additions for the Purpose of Restraining Fog," Trivelli & Jensen, *J. Frank. Inst.*, **210** (1935), 287; "Miscellaneous 'doctors,'" Middleton, *Brit. J. Phot.*, **75** (1928), 512.

Classes of Sensitizing Dyes.—Sensitizing dyes, like other dyes, are divided into acid, basic and possibly neutral classes.

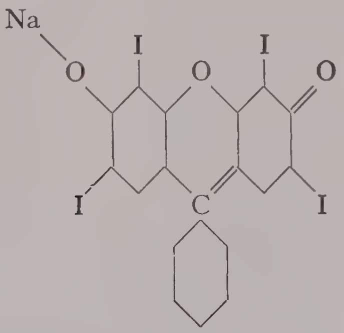
The Acid Dyes. The acid class includes such dyes as Eosin, Erythrosin, Rose Bengal, Aurine and a new type of dye recently discovered in Germany with the general formula of:



y = Sulfur, Selenium or Tellurium. If
y = S the dye is 3(2) Thianaphthenone.

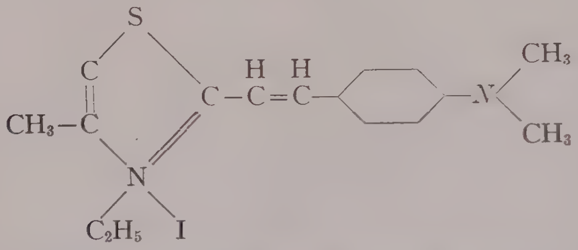
The methine group may also be replaced by a chain of 3 or 5 methine (=CH—) groups. The sensitizing intensity of this type of dye is much lower than that of the cyanines and their technical importance is doubtful.

Eosin, Erythrosin, Rose Bengal and Aurine belong to the triphenylmethane class and contain hydroxyl (OH—) groups, which characterize them as of the acid type. Of these dyes, only Erythrosin is of any importance as a sensitizer at the present time. It is used alone or in connection with a thiacarbocyanine or an oxacarbocyanine dye. Its formula, which typifies the triphenylmethanes, is:



The Basic Dyes. These include the cyanines as a general class, the pinaflavols and a few dyes of the triphenylmethane series. Auramine, ethyl violet, methyl violet, magenta and other similar dyes of the triphenylmethanes were used before the cyanines were developed, but are of no importance at the present time.

The pinaflavol sensitizers were first introduced from Germany in 1920. Bloch and Hamer of England have given a review[1] of this series of dyes, referring to them as the "styryl" compounds. There are desensitizers as well as sensitizers among the pinaflavols. They are characterized by the styryl group, $-CH=CH-C_6H_5$. The following is the structural formula of a typical pinaflavol, which is said to be a strong green sensitizer:



It is observed that the pinaflavols have an even number of carbon atoms in the linking chain, while the cyanines have an odd number.

The cyanine dyes are by far the most important of the optical sensitizers. The record of developments in this field, especially in the last 15 or 16 years, has been phenomenal. Several volumes could be written on this subject. Those who have been foremost in the development and production of the dyes are: Mills, Pope and Hamer, and their associates in England; and research workers of the German dye firms. Since about 1930, Kendall of Ilford Ltd., England, and Brooker of the Eastman Kodak Company have been the foremost leaders in the field of cyanines. W. König of Dresden has been outstanding in the development of certain important intermediates for the long chain cyanines.

The Neutral Dyes. The Rhodanine dyes developed independently by Kendall of Ilford[2] and Brooker of Kodak[3] are examples of this class. Little has been published about these dyes, and little is generally known concerning their sensitizing properties. Rhodanine and a typical sensitizer of this class have the following structural formulas respectively:

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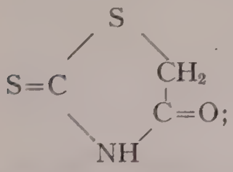
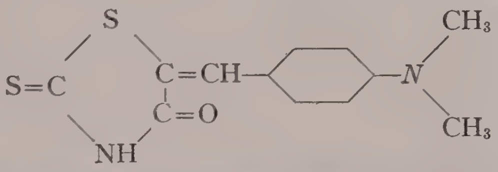
[1] *Phot. Jl.*, **70** (1930), 374–390.

[2] Kendall, *J. Soc. Dyers Colourists*, **52** (1936).

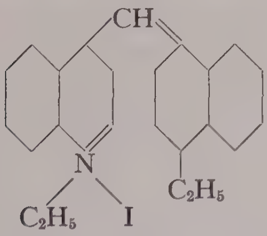
[3] Kodak Ltd. (L. G. S. Brooker) B.P. 479,970.



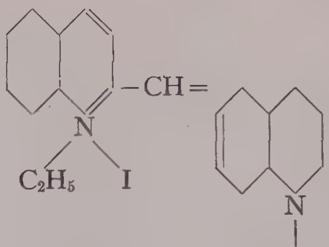


The basic character of this sensitizing compound is contributed by the ternary nitrogens, while the acid character is due to the presence of the ketonic oxygen.

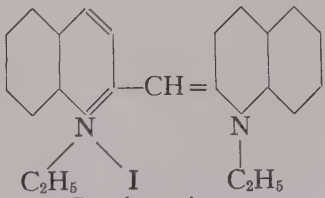
Classification and Constitution of the Cyanines.—In the early stages of the development of the chemistry of the cyanines, these compounds[4] were divided into cyanines, isocyanines and pseudocyanines. Sometime after the introduction in 1905 of a class of dyes, later known as the carbocyanines,[5] the cyanines were further classified as pinacyanols, dicyanines and kryptocyanines. After the constitutions of these compounds were established in 1920 by Mills and Hamer[6] cyanines were further classified generally into simple cyanines, carbocyanines, dicarbocyanines and so on with sub-classes of cyanine, isocyanine and pseudo- or Ψ cyanines. The following formulas illustrate the constitution and classifications just given:



Cyanines



Isocyanines



Pseudocyanines

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[4] Mills and Pope, *Phot. Jl.*, 60 (1920), 183–202.

[5] Mills and Pope, *Phot. Jl.*, 60 (1920), 253–267.

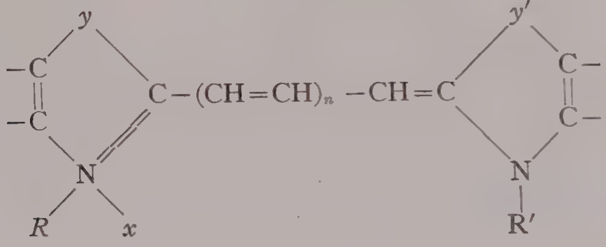
[6] Mills and Hamer, *J. C. S.*, 117 (1920), 1550–1562.

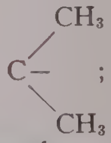
The structure of the pinacyanols, dicyanines and kryptocyanines correspond to the structures of the simple cyanines, isocyanines and pseudocyanines respectively, except in the length of the chain linking the heterocyclic rings.

The linking of the structures just given is by a single $=CH-$ group while the pinacyanols, etc., have a 3 carbon linkage, e.g. $=CH-CH=CH-$.

Following the determination of the general structure of the carbocyanines, the most important development from 1920 to about 1930 was the extension of the cyanine system by the introduction of thiazole, selenazole, oxazole and indolene ring systems. This work was carried out independently by Mills, Pope, Hamer and their associates in England, and to a lesser extent by König and others in Germany.

The chemistry of the cyanines in general has been well established, and it is believed that all the cyanines can be related by a general formula:





where y, y' may be $-CH=CH-$, $-S-$, $-Se-$, $-O-$, or $-C(CH_3)_2-$;
R, R' = alkyl group; $n = 0, 1, 2, 3, 4$ etc.; y' may be equal or unequal to y.

The nomenclature is somewhat confusing because various methods of naming the cyanines by classes and subclasses is used. The cyanines as a general class are divided, in England and America, into simple cyanines, carbocyanines, dicarbocyanines, tricarbocyanines, tetracarbocyanines and pentacarbocyanines, while in Germany, they are divided into monomethine, trimethine, pentamethine, etc., according to the number of $=CH-$ or methine groups in the chain linkage.

In 1922, König[7] suggested that the common names of the dyes, such as cyanine, isocyanine, pinacyanol and kryptocyanine be dropped, and in their place the general term quinocyanine for the dyes derived from quinoline be used, e.g., in which *y* or *y′* is $—CH{=}CH—$. This would distinguish them from the corresponding thiazole, selenazole, oxazole and indolene compounds respectively. However, the term quinocyanine has not been generally adopted.

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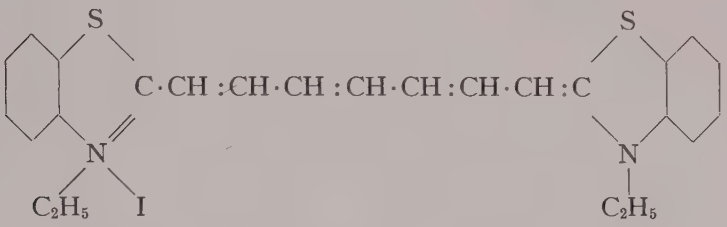
[7] König, W., *Ber.*, **15** (1922), 3293–3313.

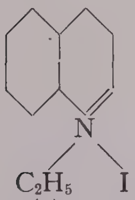
The naming of compounds from the viewpoint of the molecular structure is illustrated by the compound 2, 2′-diethyl thiatricarbocyanine iodide which is a dye with seven methine groups in the chain linkage with *y* and *y′* as sulfur. The structural formula is:



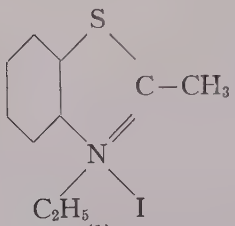
Thia represents the benzthiazole group. For more detailed information, reference can be made to the Chemical Abstracts volume on terminology.

Intermediates for the Cyanines.—The substances classed as direct intermediates or what are known as beginning materials for preparation of the actual dyes, may be divided into two classes, e.g. (1) Cycloammonium salts and (2) Linking agents for these salts.

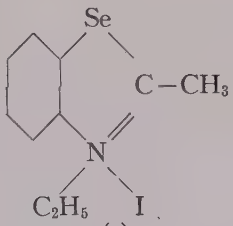
(*1*) *Cycloammonium Salts.* The most commonly used are, (*a*) quinaldine ethyl iodide, (*b*) 2-methylbenzthiazole ethyl iodide, (*c*) 2-methylbenzselenazole ethyl iodide, (*d*) 2-methylbenzoxazole, (*e*) 1, 2, 3, 3-tetramethyl indolenium iodide. The structural formulas are as follows:



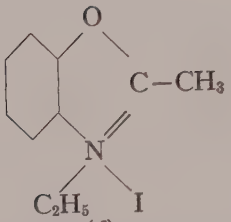
(*a*)



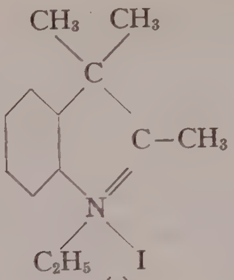
(*b*)



(*c*)



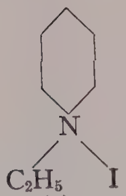
(*d*)



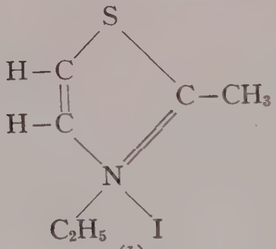
(*e*)

These compounds may be considered as derivatives of quinoline, benzthiazole, benzselenazole, benzoxazole and dimethyl indole or dimethylbenzpyrrole respectively, although it is understood that the cycloammonium salts are not prepared directly from these substances.

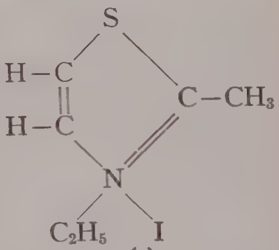
The corresponding single heterocyclic ring compounds are not used as extensively as the corresponding double ring compounds. This is probably because they are more difficult to prepare and also because the corresponding cyanine syntheses result in a poorer yield. The structures of these single membered ring compounds are:



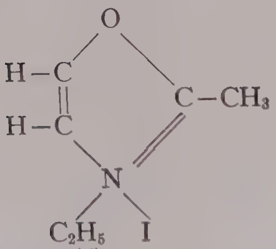
(*a*)



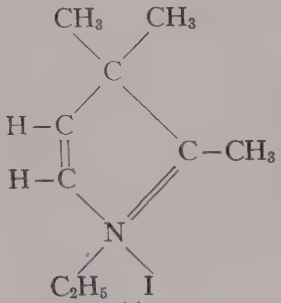
(*b*)



(*c*)



(*d*)



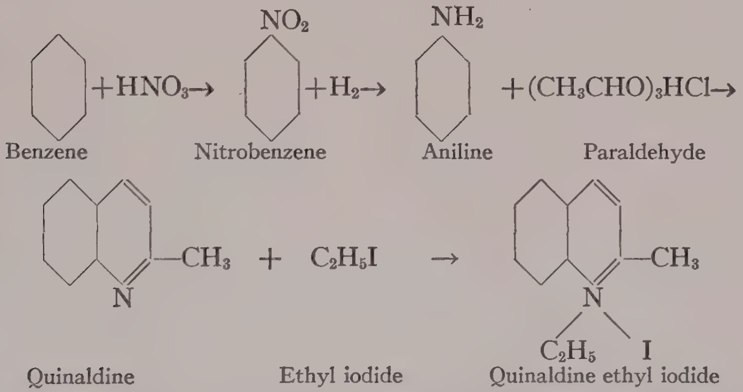
(*e*)

These compounds may be considered as derivatives of pyridine, thiazole, selenazole, oxazole and 2, 3, 3-trimethyl pyrrole respectively.

The heterocyclic nuclei themselves do not serve as beginning materials for the cyanines. There are other intermediates, such as 2-iodoquinoline, lepidine and others, which are important but cannot be considered in this brief discussion.

A brief resume of the preparation of a direct intermediate for cyanine dyes from the various indirect intermediates is as follows:

Benzene is nitrated to form nitrobenzene, which is reduced with nascent hydrogen to give aniline. By heating aniline and paraldehyde in presence of hydrochloric acid, a series of unusual reactions takes place resulting in the final product of quinaldine. Quinaldine is then ethylated with ethyl iodide to give quinaldine ethyl iodide. This series of reactions is represented diagrammatically as follows:



For more detailed information on the various phases of these individual reactions the reader is referred to treatises on advanced organic chemistry, special articles and the patent literature.

II. Linking Agents. All cyanine dyes are the result of the linking of two heterocyclic nuclei or rings by a methine ($=CH—$) group or a chain of methines. These linking groups are formed during the process of condensation.

Monomethines. The linking agent for the monomethines or simple cyanines is an active methyl or CH_3 group, which is contained in the molecule of the intermediate itself. For the quinocyanines, the CH_3 group must be in the alpha or gamma position to the nitrogen of the ring to be active. In case of the thio-, seleno-, oxy- or indolene compounds, the methyl group must be on the carbon atom between the respective elements S, Se, O or $=C(CH_3)_2$ and the nitrogen atom of the ring—e.g. the 2-position for the 5 membered rings.

Trimethines. The first substance used as a linking agent was formaldehyde. It is of importance only because it was discovered in 1905 that by using this compound a new type of dye could be obtained. It was used as the linking agent in the preparation of all of the various carbocyanines up to about 1922. The orthoformic acid esters were discovered in 1922 and since then have been used very extensively.

There are many other substances used as linking agents for the carbocyanines, as shown by the patent literature. Some of these are: the ortho esters of propionic acid, *n*-butyric, *n*-valeric, *n*- and isocaproic, phenylacetic, phenyloxyacetic and benzoic acid, tetraethyl orthocarbonic acid ester, diorthoformyl methylaminodiphenyl disulphide and diphenyl foramidine. It is believed that the use of ethyl orthoformate gives better results in most cases for the preparation of the carbocyanines than any of the other linking intermediates.

Pentamethines (Dicarbocyanines). The most important linking agent for the preparation of the pentamethines is beta-ethoxyacrolein acetal. It was probably used as the first linking agent in the preparation of cyanines of this class. The preparation of the dye was based on the ideas contributed by König.[8] Kendall (B.P. 390,808) used an acetal of propargyl aldehyde to prepare dicarbocyanines.

Heptamethines (Tricarbocyanines). The most important linking agent for the dyes of this class is glutaconaldehyde, dianil hydrochloride and what is described in the literature as the free form of glutaconaldehyde set free by the action of NaOH solution on 2, 4-dinitrophenyl-pyridinium chloride. The tricarbocyanines were discovered independently by three groups of workers of whom Wahl in Germany was the first (D.R.P. 499,967/1928). Miss Hamer of England (B.P. 351,555/1930; 354,826/1930) and Piggott and Rodd of England (B.P. 355,693/1930) also prepared tricarbocyanines using this linking agent.

The work of all three groups is based, *first* on the work of Zincke and his co-workers in Germany about 1904–1905, who showed that the pyridine ring of 2, 4 dinitrophenyl-pyridinium chloride may be broken open in an usual manner, to give 2, 4 dinitroaniline and presumably the enolic form of glutaconaldehyde and *secondly,* on the "displacement process" of König.

Nona- and Undecamethines (Tetra- and Pentacarbocyanines). The linking agent for the nonamethines is the residue of 4-acetoxy-△ 3, 5-heptadiene-1, 7-dial di-tetrahydroquinonolide perchlorate; its preparation is believed to be chiefly the result of the researches [9] of W. König, and others in Germany.

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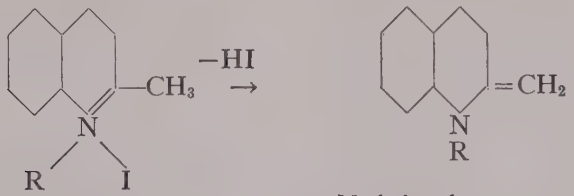
[8] König, W., *J. prakt. Chem.* (2), **86** (1912), 173.

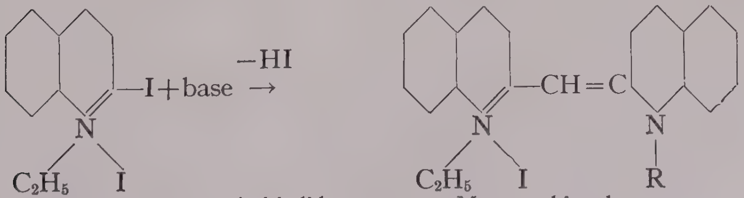
The linking agent for the undecamethines or pentacarbocyanines is 4-acetoxy-Δ 3, 5, 7-nonatriene-1, 9-dial di-tetrahydroquinalide perchlorate.[9]

Preparation and Some Properties of the Cyanines.—The fundamental conceptions developed in the realm of free research have contributed very much to the development of the cyanine dyes. Examples are the syntheses of Skraup and of Döbner and von Miller about 1885 in the quinoline series; the work of Kaufman and Vonderwahl about 1912 on the constitution of the monomethines, and that of Zincke and his asociates about 1904 on the rupturing of the pyridine nucleus which made possible the development of the tricarbocyanines. However, most of the work in the development and preparation of the cyanine dyes has been carried out in the laboratories of the photographic industry.

Monomethines. The monomethines or simple cyanines are prepared by condensing two cycloammonium salt molecules one of which contains an active methyl group. NaOH, KOH or an organic amine in alcoholic solution are used as condensing agents. It is believed that the mechanism of the reaction in the preparation of the dye consists in the removal of acid (HX) from the cycloammonium salt to give a free but unstable methylene base which unites with a second molecule of a salt to form the dye. The following diagrams will illustrate the preparation of a pseudocyanine,



Cycloammonium salt Methylene base



2-Iodo quinoline ethyl iodide Monomethine dye

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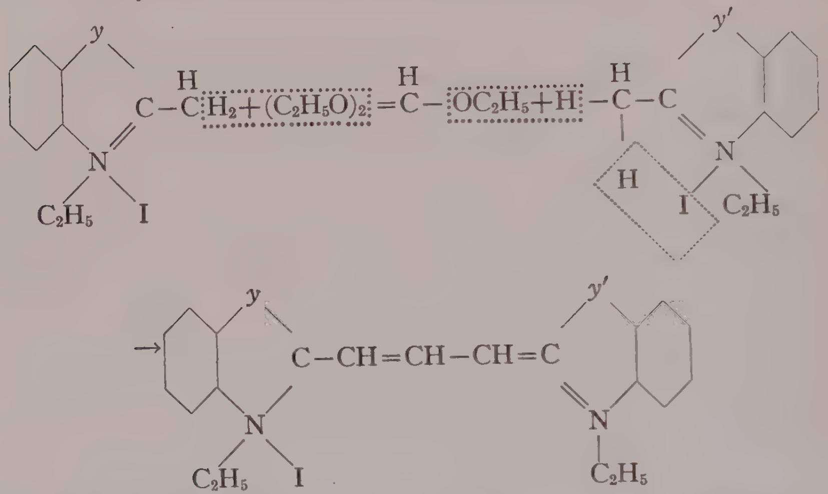
[9] *Ber.*, 67 (1934), 1274.

The isocyanines and cyanines are prepared by similar methods but using different cycloammonium salts.

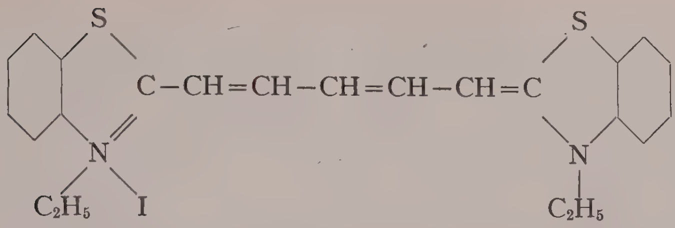
Trimethines (Carbocyanines). The patent literature indicates that the carbocyanines are the most numerous of all the cyanines. Mills and Pope in an article in the *Photographic Journal* of 1920 have given methods for the preparation of about 18 different dyes. Formaldehyde was used as the linking agent and sodium or potassium hydroxide as the condensing agent. Since the use of orthoformic acid ester has supplanted the formaldehyde method, the following diagram using ethyl orthoformate will be used as an illustration of the preparation of a carbocyanine.



where y = —CH = CH—, —S—, —Se—, —O—, or —C $(CH_3)_2$—; y may or may not equal y'.

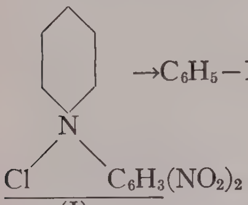
The first dye of technical importance in this group was Pinacyanol which, however, has largely been replaced by other dyes. The carbocyanines are very important since they give ranges of sensitization chiefly in the visible range of the spectrum.

The Pentamethines (Dicarbocyanines). The dicarbocyanines are not considered as important as the tri-, tetra- and pentacarbocyanines. The most important method of preparing these compounds is by the condensation of two cycloammonium salt molecules with one molecule of beta-ethoxyacrolein-acetal. As may be expected, the reactions are very complex and cannot be considered in a brief discussion. The sulfur dyes of this class are probably the most important. A typical dicarbocyanine is:



The dyes of this class are sensitizers for the red and infra-red.

Heptamethines (*Tricarbocyanines*). As has been stated under "Linking Agents," the most important direct intermediate in this class is glutaconaldehye in the form of its dianil hydrochloride. The development of the dyes of this class is based largely on the work of Zincke and the "displacement process" suggested by König. Zincke and his co-workers showed that the pyridine ring of 2,4-dinitrophenyl-pyridinium chloride (I) may be broken open by treating with NaOH to give the dianil of glutaconaldehyde. This substance (II) which is classed by König as a streptopolymethine dye is then subjected to the "displacement process" of König by condensing with two cycloammonium salt molecules in absolute alcohol in presence of sodium ethoxide to produce a tricarbocyanine dye. The formulas and processes are represented diagrammatically as follows:

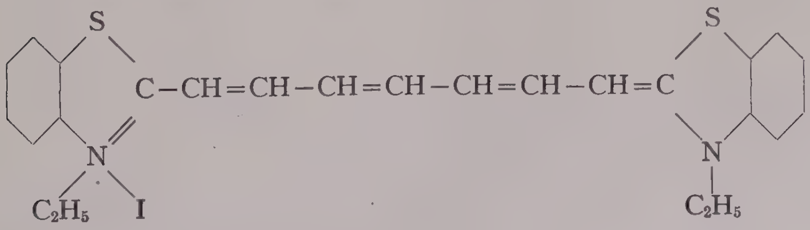


(I)

$$\rightarrow C_6H_5-N=CH-CH=CH-CH=CH-NH-C_6H_5$$

II

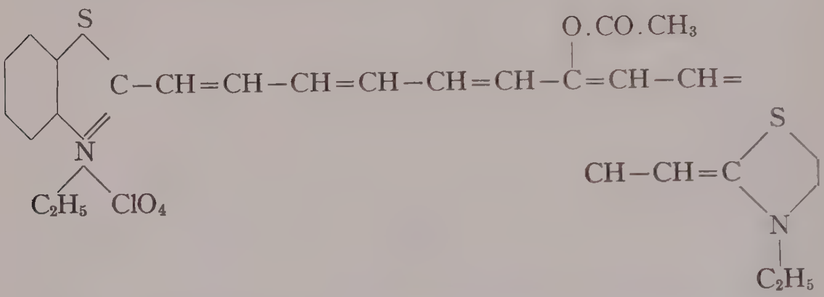
Formula (II) or a streptopolymethine is condensed with 2 molecules of 1-methyl-benzthiazole-ethyl iodide to give the dye 2,2-diethyl benzthiotricarbocyanine iodide the structural formula of which is:



The "displacement process" of König[10] consists in the replacement of a $C_6H_5N=$ and a C_6H_5NH- by the cycloammonium salt residues.

The tricarbocyanines are sensitizers for the red and infra-red.

The Nona- and Undecamethines (Tetra- and Pentacarbocyanines). These dyes are sensitizers for the extreme infra-red. The preparation of these dyes is the result of the work of König[11] and others in Germany based on König's "displacement process" of 1912. A typical formula, of a pentacarbocyanine dye, is:



As to the future of the long chain cyanines, the importance depends on the stability of the dyes formed. The tetra and pentacarbocyanines are somewhat unstable. The desire of the present day is to remove the side-chain or oxacyl group from the linking chain.

Process of Sensitization.—Considerable work has been carried out to determine the action of dyes in the various photographic processes, the results of which are not considered here. However, it is believed and generally accepted that the dyes are adsorbed on the silver halide in some way, but the exact mode of action of these small traces of dye, which in some cases is only several parts of dye per million of silver halide, is still unsolved.

The relation of chemical structure to sensitization is very interesting. Examination of the chemical structures of the sensitizing dyes shows a common feature in all the classes of dyes which are actual sensitizers. There is a conjugated chain containing an odd number of carbon atoms linking a quaternary nitrogen and a ternary nitrogen in the basic series, and a ketonic oxygen linking a hydroxy-oxygen in the acid series, e.g.,

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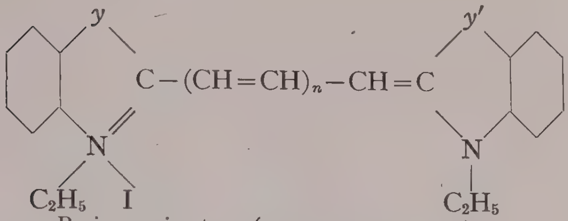
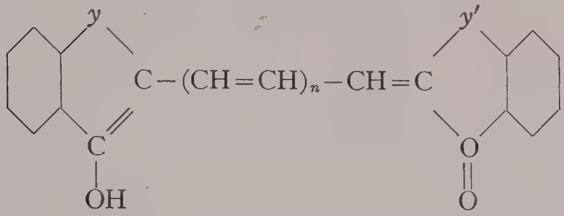
[10] König, W., *J. prakt. Chem.* (2), 86 (1912), 173.

[11] *Ber.*, 67 (1934), 1274.



Basic cyanine type (n = 0, 1, 2, 3, 4, etc.)



Acid type (n = 0, 1, 2, 3, 4, etc.)

Various substitutions can be made in the chain and nuclei within certain limitations, but the effect of these substitutions is to change the spectral range of sensitization, and to change to some extent the speed of the emulsions in which the dye is incorporated.

The number of dyes which are wholly satisfactory for sensitizing is surprisingly few, when we consider the large number of dyes which can actually be prepared.

It is impossible to include here the range of sensitivity by general classes, because of the influence of various substituents both in the nuclei and the chain. This is especially true in the unsymmetrical cyanines of all classes and series. Of the cyanines in use ten years ago, very few are in actual use today. Erythrosine which is still in use today, sensitizes from 380 to 580 millimicrons, but with a gap in the blue green. In practice, it may be mixed with thiacyanines or oxacyanines to level off this gap. This practice applies for other spectral ranges using other dyes.

The progress in the development of the cyanines has been phenomenal. Those who have contributed most to this work have been comparatively few in number, but their work can be classed among the classic researches in the field of chemistry.

Preparing the Support.—The support, whether film, glass, or paper, must first be prepared to receive the emulsion. Glass is usually

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Kozloff and Podogorodetzki—Mechanism of Adhesion of the Emulsion to the Film Support. Proc. Ninth Int. Congress of Phot., Paris, 1935. 255.

coated first with a thin layer of gelatin hardened in chrome alum so as to obtain good adhesion between the emulsion and the support. This layer forms what is called a *substratum* coating.

Hardened gelatin does not adhere well to film base; because of this and to obtain an efficient substratum coating, it is necessary to employ a mixture of gelatin and cellulose nitrate dissolved in a water-miscible, organic solvent such as acetone or ethyl acetate. When this mixture is spread in a thin layer over the film base, the water and the solvent evaporate, leaving a thin coating consisting of cellulose nitrate and gelatin. The first mentioned is held firmly by the film base, which also consists chiefly of cellulose nitrate, and this, in turn, holds the gelatin necessary for good adhesion between the film and the emulsion.

Emulsion Coating Machinery.—Since late in the last century all commercial photo sensitive materials have been coated by machinery. Outside of the industry little is known of the machinery actually employed and it is probable that there is little that is common in the design of the machinery used by different manufacturers. It may be useful, however, to notice briefly some of the basic principles employed in such machines.[27]

In machines designed for coating glass plates, the cleaned glass plates are placed on a moving belt which conducts them beneath the coating apparatus. This apparatus spreads a thin and uniform layer of the emulsion over plates. Several coating devices have been described in the literature. In one of the earliest machines the emulsion simply flows over the lips of a long, narrow trough onto the glass plate. The emulsion must, of course, be kept at a suitable temperature in order that it may flow readily. In another machine described by Cadett, the arrangement is very similar except that directly behind the trough from which the emulsion issues is a light-weight roller which acts as a spreader and smooths out the layer of emulsion on the plates. In still another machine, described by B. J. Edwards, the emulsion was contained in a long trough the width of the glass to be coated. In this trough a glass cylinder is revolved. A scraper, or squeegee, on one side

[27] Machinery for the coating of photographic emulsion on glass, film and paper is supplied by August Köebig in Dresden, by Dörstling of Dresden, and by R. W. Monro Limited of London, and T. H. Dixon and Company Limited of Letchworth, England.

KIESER—Emulsion Coating Device for the Laboratory. Phot. Ind., 30 (1932), 627.

of the cylinder removes the emulsion carried around the cylinder and allows it to drain down onto the glass plate.[28]

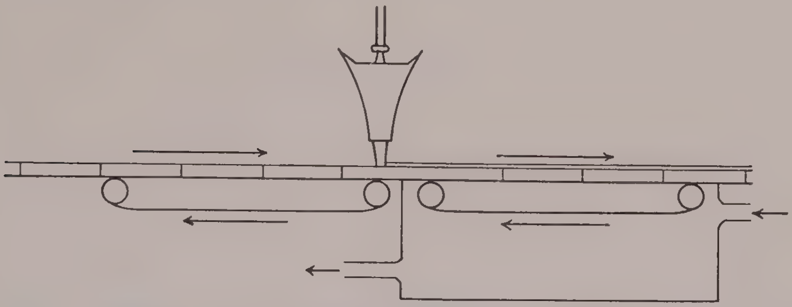

FIG. 119. Diagram of Plate Coating Machine (From Baines, *British Journal of Photography*, 1930)

After being coated with the emulsion, the plates are carried on a movable belt through a cold chamber or compartment in which the emulsion is chilled and set to a gel. Upon reaching the end of the conveyor system, the plates are removed and dried under controlled conditions.

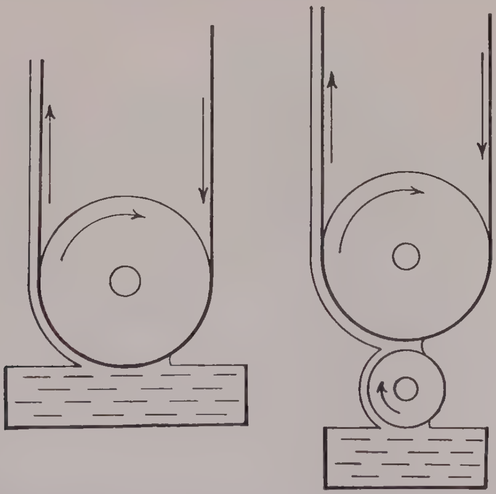

FIG. 120. Diagram Illustrating Principle of Trough and Doctor Roller Coating Machines (Baines, *British Journal of Photography*, 1930)

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[28] Smith, *Eder's Jahrbuch*, 1892, p. 385; Cadett, English Patent 9,886 of 1886, and 13,725 of 1887; Edwards, *Photographic News*, 1884, p. 541.

Film and paper coating machines differ in certain particulars from those employed for coating glass plates owing to the differences in the nature of the substance coated. The basic principles, however, are essentially the same. Both film and paper are usually coated in rolls from 36 to 54 inches in width and 1000 feet or more in length. The devices employed for applying the emulsion are somewhat different from those used on plate-coating machines since the film base is flexible and it is more difficult to obtain a uniform coating. After coating, the paper, or film, is carried over cooled drums, or in festoons through a compartment containing refrigerated air, which causes the gelatin to set to a gel. The coated film or paper is then carried automatically on festoons to a drying compartment where it is dried under controlled conditions.

The Silver Bromide Grain of Photographic Emulsions.—When examined under a high power microscope, the photographic emulsion is seen to consist of numerous semi-transparent and practically opaque grains of silver halide imbedded in gelatin. These grains of silver halide are definitely crystalline (Fig. 121)[29] and of various forms and sizes; the most constantly recurring forms being triangles and hexagons, some of which are irregular, while all have rounded corners, but occasionally a long rod-shaped crystal is observed. The

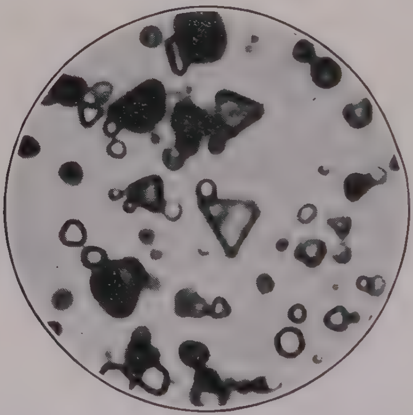

FIG. 121. Crystals of Silver Halide of a Photographic Emulsion

grains also vary in transparency, some being almost completely transparent while others are nearly opaque. Since the opaque grains behave in exactly the same way as the transparent grains, there is no justification for assuming that they are different substances. In addition to these there are ultra-microscopic grains which are beyond the limit of visibility with the highest power of the microscope. Recent investigation has shown that these are also crystalline and have substantially the same structure as those of larger dimensions. There is no evidence for the existence of non-crystalline silver bromide in photographic emulsions.

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[29] The emulsion shown in Fig. 121 has been greatly diluted in order that the individual crystals may be more clearly seen. Ordinary emulsions as used for coating of plates and film consist of many layers of such grains and contain from 10 to 25 billion of such crystals to the square inch.

The size of the silver halide grains in commercial emulsions ranges from the ultra-microscopic particles of less than one micron to grains as large as 3 or 4 microns. In positive emulsions the larger number of grains are either ultra-microscopic or very small, while in the case of highly sensitive negative emulsions, although a large number of ultra-microscopic grains are present, the majority of the grains are of microscopic size, while all are of course definitely crystalline.

The Sensitivity of the Silver Halide Grain.—Microscopical investigation has shown that in spite of the enormous number of grains of silver halide and their close proximity to one another, each individual grain affected by light acts as a single unit and there is no transference of development from one grain to another, unless the two are grouped together in absolute contact; a state of affairs characteristic of some emulsions. It has also been found that a grain is either made developable by a certain amount of light or it is not developable. Thus, we do not get partial development for a certain exposure followed by more for a longer exposure but up to a certain amount of light action the grain is undevelopable and after that amount is reached it is rendered completely developable. The amount of light required to make a grain developable represents what is termed the *sensitivity* of the grain.

Investigation of the number of grains made developable by a given exposure shows that all the grains are not equally sensitive; because under such conditions all the grains would become developable as soon as the exposure reached a certain value. Microscopical examination at high powers shows that the grains of silver halide differ widely in size and on counting the number of grains made developable in given size-classes, it is found that in one and the same emulsion the sensitivity increases with the size of the grain. This does not necessarily mean that all large grains are more sensitive than smaller ones, for with different emulsions the reverse is often true, but if we keep to the same emulsion the larger grains are on the average more sensitive than the smaller. There are, however, differences in sensitivity among grains of the same size and shape in the same emulsion. Sensitivity is, therefore, not wholly a function of the size of grain, but is due to an inherent difference in the grain itself.

Long ago Abegg and Eder suggested that in the process of digestion a trace of the silver halide is reduced to either a sub-halide, or to silver. These traces they referred to as "ripening centers." These served as centers for further reduction by light to form the latent image. The existence of specially sensitive spots in the grain of silver halide is now well established. Lüppo-Cramer and Renwick supposed these spots, centers, nuclei, or specks, as they are variously termed, to consist of colloid silver. However, the work of Sheppard and his co-workers on the sensitizing substances in gelatin seems to prove beyond all doubt that the sensitivity centers are composed of silver sulfide, which is produced as a result of a chain of reactions between the sensitizing substance and the silver halide.

These submicroscopic specks of silver sulfide are distributed at random in, or on the surface, of the grains. It is believed that they cause a strain in the crystal of silver halide creating around them a sphere of weakness in the crystal structure which increases the sensitivity of the grains.

We will leave to a later chapter a discussion of the manner in which these sensitivity centers function in the formation of the latent image.

Grain-Size Distribution and its Relation to the Photographic Properties of Emulsions.—Investigation having shown that the individual halide grain is the photochemical unit of the photographic plate, the properties of the emulsion representing simply the sum of the properties of the individual grains modified by their positions in layers, a study of the effect of grain-size distribution in emulsions and its relation to photographic properties is of great importance. For if emulsion sensitiveness is merely a matter of grain-size distribution the emulsion maker has only to provide the conditions favorable to the growth of crystals of the proper size in order to produce emulsions of the highest possible sensitiveness or having any other required properties. On the other hand, should it be shown that photographic properties are not wholly, or only partially, controlled by grain-size distribution but by other factors as well, the line of investigation must naturally be directed along entirely different lines.

Before 1895 Haddon and Banks called attention to the probability of some relation between the size of grains and the sensitiveness of an emulsion and Mees in 1915 suggested that "inasmuch as emulsions are not homogeneous, but contain grains of all sizes, the sensitiveness of the emulsion will depend upon the distribution of the different sizes of grains, as will also the shape of the characteristic curve."[30] Slade and Higson as the result of some investigations on the action of light on an emulsion containing grains of very nearly the same size and only one layer thick also concluded that the properties of the emulsion are determined mainly by the relation of the different sizes of grains to one another and the quantity of each present.[31] Svedberg found that for every class of grains of nearly the same size in the emulsion there is a distinct characteristic curve.[32]

The matter was not fully investigated until Sheppard, Wightman and Trivelli attacked the problem by photomicrographing the grains of various emulsions at a magnification of 2000 times and then enlarging the negative five times, so that the actual magnification equalled 10,000 times. The developed grains of a given area were then measured and divided into classes according to size. The data secured in this manner may be represented graphically by plotting the number of grains of each class as ordinates against the sizes of the grains as abscissae. In Fig. 122 are shown photomicrographs of the

[30] *J. Franklin Inst.*, **179** (1915), 141.
[31] *Phot. Jl.*, **59** (1919), 260.
[32] *Z. Wiss. Phot.*, **20** (1920), 36.

Sheppard—Dispersity of the Silver Halides in Relation to their Photographic Properties. First Colloid Symposium Monograph, 1923.

Sheppard—Grain-size and Distribution in Emulsions. Phot. J., **65** (1925), 31.

Sheppard, Wightman and Trivelli—Size-Frequency Distribution of Particles of Silver Halide in Photographic Emulsions and its Relation to Sensitometric Characteristics. I. J. Phys. Chem., **25** (1921), 181; II. Ibid., **25** (1921), 561; III. Ibid., **27** (1923), 1; IV. Ibid., **27** (1923), 141; V. Ibid., **27** (1923), 446.

Sheppard, Trivelli and Wightman—Relationship of Photographic Emulsion Fog to Grain Size. Phot. J., **65** (1925), 134.

Sheppard and Trivelli—Sensitivity of Silver-Halide Grains in Relation to Size. Phot. J., **67** (1927), 284–287.

Svedberg—Size and Sensitiveness of the Grains in a Photographic Emulsion. Zeit. wiss. Phot., **20** (1920), 36.

Svedberg—On the Relation between Sensitiveness and Size of Grain in Photographic Emulsions. Phot. J., **62** (1922), 186.

emulsion of a portrait film and a Standard slow lantern plate together with curves showing the size-frequency distribution of each. It will be observed that the grains of the positive emulsion are all compara-

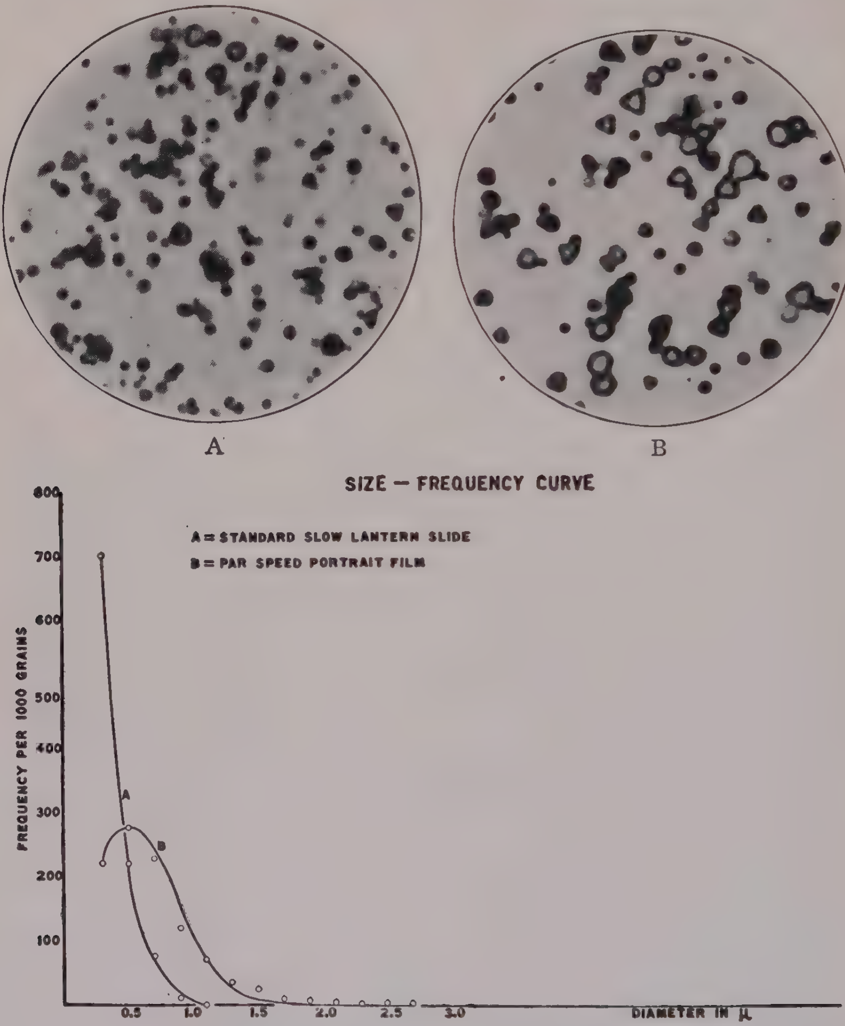

FIG. 122. Size Frequency Distribution of Silver Halide Grains in a Portrait Film and Lantern Slide Emulsion

tively small and uniform, the range being from about 0.2 to 1 micron. The high speed portrait film, on the contrary, shows an extended range of sizes from about 0.2 micron to as high as 2.7 microns with a maximum close to 0.5.

A correlation of these facts and the photographic properties of emulsions is to be the subject of further investigation. The data which has been accumulated shows definitely that the relative speed of an emulsion increases rapidly with an increase in the average size, and range of size, of the grains contained in the emulsion. Several other interesting relations have been indicated in the course of the investigation and these points are now being investigated. At the present time all that can be definitely stated is that there is apparently a very close connection between grain size and size-frequency and the photographic properties of emulsions.

CHAPTER VI

THE LATENT PHOTOGRAPHIC IMAGE

The Visible Darkening of Silver Halides to Light.—All three of the halides of silver, the chlorine, bromide, and iodide, darken visibly on exposure to light. Scheele showed in 1777 that when silver chloride darkens the halogen is liberated. As a result of the work of Schwarz and Gross,[1] and particularly of Hartung [2] using a specially sensitive micro-balance, it is now well established that in the case of all three halides, halogen is liberated when visible darkening takes place. The presence of substances which by absorbing halogen act as "halogen acceptors" increases the degree of darkening and Hartung has shown that silver bromide *in vacuo* in the presence of a bromine acceptor can result in the loss of over 90 per cent of the bromine. The darkening *in vacuo* in the absence of a halogen acceptor is slight and impermanent.

It was formerly believed that the result of the liberation of halogen was the formation of a sub-halide, that is, a halide containing less halogen than the normal. Attempts to prepare definite sub-halides of silver in the laboratory have met with conflicting success, and it appears that the sub-halides of silver which were prepared by Von Bibra [3] and Vogel,[4] for example, are compounds of finely divided silver and unaltered silver halide. The photosalts of Carey Lea were regarded as definite sub-halides by their discoverer but subsequent investigation has shown these to be absorption-compounds of colloid silver with silver halides.

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[1] *Z. Anorg. Chem.,* **133** (1924), 389.

[2] *J. Chem. Soc.,* **125** (1924), 2198.

[3] *J. für Prak. Chem.,* **2,** 12–55.

[4] *Phot. Mitt.,* **36,** 334.

Guntz—The Action of Light on Silver Chloride. Phot. J., **45** (1905), 131.

Hartung—Photochemical Decomposition of Silver Chloride. J. Chem. Soc., **127** (1925), 2691–2698.

Hartung—Photochemical Decomposition of Silver Iodide. J. Chem. Soc. (1926), 1349–1354.

Stock—The Photo-chemical Decomposition of Silver Bromide. Zeit. wiss. Phot., **24** (1925), 132.

Trivelli and Sheppard—Visible Decomposition of Silver Halide Grains by Light. J. Physical Chem., **29** (1925), 1568–1581.

The work of Schwarz and Gross and that of Hartung has at last shown quite definitely that the products of the visible decomposition of the silver halides in light are metallic silver and halogen.

The Latent Photographic Image.—When light is allowed to fall on a photographic plate, or upon silver halide precipitated from solution, the silver bromide is altered in some unknown way because a reducing agent, or "developer," is able to darken the silver bromide exposed to light more rapidly than that which has not been exposed. We say that the light has produced a "latent image" because it is invisible to the eye but susceptible of reduction to metallic silver by certain reducing agents. The nature of this latent image is still an unsolved problem, despite much speculation and an enormous amount of experimental work.

Before proceeding to discuss the theories of the latent photographic image, however, a brief survey of the methods of producing a latent image and the reactions of the developable image is necessary to prepare the way for a discussion of the various theories.

Artificial Latent Images.—A developable photographic image may be produced without light by exposing the sensitive material to certain vapors or by bathing in solutions of certain substances.

The vapors of many fats and volatile oils, as well as those of a number of organic substances, render the silver halide developable. The action has been attributed to hydrogen peroxide which exhibits the same effect.

The result obtained by bathing unexposed photographic materials in hydrogen peroxide and developing parallels the results obtained by exposure to light very closely. For example, the density produced upon

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CLARK—Action of Arsenites on the Photographic Plate. Brit. J. Phot., 72 (1925), 155.

CLARK—Sodium Arsenite and the Plate. Brit. J. Phot., 70 (1923), 717.

CLARK—Fogging Action of Hydrogen Peroxide. Phot. J., **66** (1926), 78–84.

RUSSEL—Action of Resin and Allied Substances on the Photographic Plate. Phot. J., **39** (1899), 345.

SHEPPARD, WIGHTMAN AND TRIVELLI—Action of Arsenite and Oxidizing Agents. J. Frank. Inst., **198** (1924), 629.

WIGHTMAN—Fogging Action of Persulphate. Brit. J. Phot., **74** (1927), 447–448.

WIGHTMAN AND QUIRK—Intensification of the Latent Image on Photographic Plates and Films. II. Decomposition of Hydrogen Peroxide and the Mechanism of Latent Image Intensification. J. Franklin Inst., **204** (1927), 731–749.

treating an emulsion with hydrogen peroxide increases with the time of treatment, assuming a solution of given concentration, or, for a given time of treatment, with the concentration of the solution producing, upon development, a curve similar in form to the well-known f-shaped characteristic curve produced by exposure to light. On prolonged treatment with peroxide, the curve shows a definite reversal portion, as in the case of exposure to light. The curve obtained by bathing in hydrogen peroxide is also affected by development in the same way as the D log E curve. Plates most sensitive to light are also most sensitive to peroxide, and the larger grains in an emulsion are, on the average, more sensitive than the smaller ones to both light and peroxide.

Similar results are obtainable with sodium arsenite.

If a latent image produced by light is treated with a solution of hydrogen peroxide whose concentration is lower than that producing a fog image, and then developed, the developability of the image is increased thus intensifying the latent image.[5]

The reaction taking place is not clear nor has it been possible to put it to use practically as a means of reducing exposure.

Development After Fixation.—The latent image is not destroyed by fixing, and an exposed film may be developed after fixing, by employing a solution of acid silver nitrate, containing a reducing agent in which collodial silver will be precipitated. The reducing agent must be a developer in the usually accepted sense (metol, diaminophenol, etc.); other reducing agents, such as formaldehyde, which will form colloid silver do not develop a latent image.[6]

Action of Oxidizing Agents on the Latent Image.—The latent

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[5] S. E. Sheppard and E. P. Wightman, *J. Franklin Inst.*, **195** (1923), 337. Wightman, *Brit. J. Phot.*, **74** (1927), 447. Wightman, Trivelli, and Sheppard, *J. F. I.*, **200** (1925), 335. Wightman and Quirk, *J. F. I.*, **203** (1927), 261; **204**, 731.

[6] Young, *Photographic News*, 1858, **I**, 165. Kogelmann, *Die Isolierung der Substanz der Latenten, Photographischen Bilder.* Graz, 1899. Sterry, *Photography*, 1898, p. 260. Neuhauss, *Phot. Rund.*, 1899, **36**, 257, and 1904, **41**. Lumiere & Seyewetz, *Bull. Soc. franç. Phot.*, 1911, p. 264, 373 (1924). *Compt. Rendus*, 1924, **179**, 14. Lüppo-Cramer, *Phot. Rund.*, **61** (1924), 780. Owens, p. 202. Bullock, "Reactions of Latent Image," *Phot. Revue*, **37** (1925), 48; *Phot. Jl.*, **69** (1929), 278.

LUMIERE AND SEYEWETZ—Development of the Latent Image after Fixing. Compt. rend., **178** (1924), 1765.

OWEN—Physical Development and Nature of the Latent Image. Phot. J., **69** (1929), 278–280.

image is either reduced or entirely destroyed by oxidizing agents. Substances such as potassium cyanide, acid potassium permanganate, acid ammonium persulfate, chromic acid, when used with sulfuric acid or potassium bromide, and cupric, ferric and mercuric salts, when used with a halide, completely destroy the latent image.

Destruction of the latent image by oxidizers, however, does not necessarily result in the destruction of the sensitivity of the unexposed emulsion. Chromic acid, for example, reduces the latent image much more than it does sensitivity and with ammonium persulphate the difference is even greater. The reduction in the sensitivity of the unexposed grains varies with the size of the grain, being greater for the large grains than the small. If the sensitivity centers of the grains consist of silver sulfide, as indicated by the work of Sheppard, and the latent image of colloidal silver, then it is evident that the difference can be explained as being due to the greater resistance of the latter to attack. Experiments by Clark on silver and silver sulfide solutions seem to indicate that this is the case.[7]

Reversal.—With a short exposure, the latent image develops as a negative. If the exposure is greatly increased the image develops as a positive rather than a negative. Reversal is delayed by derivatives of hydrazine, phenylenediamine, sodium nitrite and certain other substances which absorb free halogen and is facilitated by solutions of sodium arsenite, peroxide, permanganate, persulfate and dichromate.

In the reversal process with light it is probable that the function of prolonged exposure is to make the deposition centers inactive again. It is suggested by some that this could occur by some sort of "retrogressive" action, the centers reverting to their original state; but actually such a reversion seems to be thermodynamically impossible as long

[7] Bullock, *Chemical Reactions of the Latent Image,* D. Van Nostrand Co., N. Y., 1927. Extensive Bibliography.

Bullock—Oxidizing Agents and the Latent Image. Brit. J. Phot., **74** (1927), 590–591.

Clark—Oxidizing Agents in the Study of the Sensitivity of Photographic Emulsions. Brit. J. Phot., **74** (1927), 227–228, 243–245.

Sheppard, Wightman and Trivelli—Effect of Oxidizers on the Sensitivity and on the Latent Image. J. Frank. Inst., **198** (1924), 507.

Sterry—The Action of Oxidizers on the Latent Image. Phot. J., **47** (1907), 170; Brit. J. Phot., **54** (1907), 166, 171, 206; Eder's Jahrbuch, **21** (1907), 364.

Sheppard and Mees—Action of Substances on the Latent Image. Phot. J., **47** (1907), 65; Brit. J. Phot., **54** (1907), 33.

as the light stimulus is acting. The more probable result of prolonged exposure is so to change the centers as to make them no longer able to function in development. How this occurs is not clear. In the case of arsenite, however, a very satisfactory explanation is found in assuming that, on prolonged treatment, the arsenite peptizes the nuclei formed during the first stages of its action, and so makes them too small to function in development. This view is supported by experimental observation that sodium arsenite can peptize colloidal silver in gelatin, and also that it can destroy the latent image left after fixation of an exposed plate, so that it cannot be physically developed.

It is seen then, that although latent image formation is similar in the case of arsenite and of light, the reversal process is probably quite different in the two cases. The presence of the latent image alone is a sufficient condition for reversal by arsenite, but for reversal by light, the silver halide itself must also be present. Hydrogen peroxide solution can also peptize colloidal silver and destroy the latent image, so that an explanation of reversal by peroxide solution similar to that advanced for arsenite is satisfactory. In the case of reversal by exposure to hydrogen peroxide vapor, however, it is more difficult to conceive that it is due to peptization.

Photo-Regression.—The gradual disappearance of the latent image after exposure is termed photo-regression. The latent image is remarkably permanent and instances are on record where plates and films have been successfully developed twenty years or more after exposure.[8]

With developing out papers the latent image fades rapidly and is noticeably weaker on most papers the day after the exposure.[9]

The disappearance of the latent image is greatly accelerated by heat and dampness.

Theories of Latent Image Formation.—The reaction taking place when a silver halide is exposed to light and the nature of the latent, or developable, image has long been a source of speculation.

[8] Cannon, *Phot. Jl.*, 57 (1917), 72.

[9] Bennett, *Brit. J. Phot.*, 75 (1928), 200.

Carroll and Kretchman—Photographic Reversal by Desensitizing Dyes. Bur. Stand. J. Res., **10** (1933), 449.

Clark—Reversal by Hydrogen Peroxide, Sodium Arsenite and Light. Phot. J., **64** (1924), 363.

Strauss—The Retrogression of the Latent Image. Kinotechnik, **6** (1924), 315.

In some quarters it has been assumed that the latent image differs from the visible image only in degree and not in kind and that the result of exposure to light is to liberate halogen forming either a sub-halide of silver (i.e., one containing less halogen than the normal halide) or metallic silver. The sub-halide theory appears to have been suggested by *Berthollet* and was strongly supported for many years by some of the most eminent authorities.[10] However, attempts to prepare silver sub-halides in the laboratory have met with contradictory and inconclusive results except in the case of the sub-fluoride which was isolated by Guntz and confirmed by Wohler. The silver sub-halide theory is now of historical interest only.

The theory that the latent image consists of silver appears to be due to Guthrie (1850). He thought that the action of light resulted in the formation of small centers of metallic silver on which the image is built up by the deposition of silver from the developing solution. (It will be remembered that at this time acid developers containing silver were in general use.) The fact that the latent image is destroyed by nitric acid was advanced as being proof that it consisted of silver. However, it can be shown that other substances which attack finely divided silver are without effect on the latent image so the evidence is inconclusive. The silver theory has undergone considerable transformation in recent years and as the *colloid silver* theory is accepted in many quarters as the theory which is most nearly in accord with the known facts.

According to the colloidal silver theory, a sensitive emulsion consists not simply of silver halide in gelatin but a trace of a highly unstable form of colloidal silver in solid solution formed as a result of reduction of some of the silver halide to silver in digestion with heat or ammonia. Renwick advanced the theory that the action of light is to coagulate

[10] Waterhouse, *Phot. Jl.*, **47** (1903), 59.

ALLEN—The Formation of the Image on the Photographic Plate. Phot. J., **54** (1914), 175.

ARENS AND LUFT—Present Position of the Theories of the Latent Photographic Image. Veroffent. wiss. Zentral-Lab. phot. Abt. Agfa, **4** (1935), 1.

BAKER—Formation of the Latent Image. Brit. J. Phot., **76** (1929), 532–533.

BANCROFT—The Latent Image. J. Phys. Chem. (1912); Brit. J. Phot., **59** (1912), 881.

BELLIOT—A Theory of the Latent Image. Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 323.

amicrons of colloid silver to form larger particles which serve as centers for development.

Through the years there has been another school of thought which regards the energy required to make a photographic material developable as insufficient to produce any appreciable decomposition in the silver halide. Out of this objection to the view that the latent image involves a chemical change in the nature of the silver halide have grown certain "physical" theories. These involve the formation of an internal strain within the silver halide molecule which renders it unstable and therefore more readily reduced by developers (*molecular strain theory*), the breaking down of the silver halide crystal into smaller particles which are more readily attacked by the developer (*disintegration theory*) or the discharge of an electron, or electrons, leaving an unstable silver halide crystal (*photo-electric theory*).

The X-ray analysis of crystals, however, leads to the conclusion that no chemical molecule in the sense of a specially combined atom pair exists, but rather a space lattice structure of silver ions and bromine ions held together by the electrostatic attractions of the oppositely charged ions, and under such conditions there is little basis for physical theories which involve a molecular strain.

In recent years, it has become widely held that the action of light, in the formation of the latent image, causes the bromine ion in the silver halide to lose an electron, which is then accepted by a silver ion to form a metallic silver atom, so that the latent image consists of small centers of metallic silver on the surface of the silver halide grains. Direct, analytical, chemical proof of this hypothesis is of course difficult owing to the infinitesimal quantities of silver involved; the only evidence in support of such a hypothesis is that afforded by the chemical reactions of the latent image. These, however, are inconclusive.

Luppo-Cramer—History and Theory of the Latent Image. I. Zeit. wiss. Phot. **23** (1924), 91; II. Ibid., **23** (1925), 122; III. Ibid., **23** (1925), 216.

Rawling—The Mystery of the Latent Image. Phot. J., **63** (1923), 482.

Rawling—Recent Advances in our Knowledge of the Latent Photographic Image. Phot. J., **69** (1929), 471–478.

Renwick—Photographic Images—Visible and Invisible. Brit. J. Phot., **67** (1920), 447, 463.

Renwick—The Gelatine Emulsion and the Latent Image. Brit. J. Phot., **70** (1923), 382.

Sheppard—Formation of the Photographic Latent Image. Phot. J., **68** (1928), 397–413.

Investigations by Toy of the photo-electric properties of the silver halides lend additional support to the hypothesis suggested. It has been known for a long time that the silver halides possess both photo-electric and photo-conductivity properties. By the former is meant the complete liberation of electrons from the salt under light action, and by the latter (sometimes called the internal photo-electric effect) the freeing of electrons internally, resulting in a change in conductivity. Theories of the latent image based on the photo-electric effect were brought forward by Allen and by Audubert, but Toy has shown that the silver halides do not show the true photo-electric effect at wave-lengths greater than 280 mμ while the photographic effect of light, of course, extends to much longer wave lengths than this, so that there is, apparently, little foundation for a photo-electric theory of photographic exposure.

While the silver halides do not exhibit the true photo-electric effect under the conditions of ordinary exposure, there are so many striking similarities between the photo-conductivity effect with the silver halides and the photographic effect that one is inevitably led to the conclusion that both are due to the loosening of electrons from the halide ions.

The photo-conductivity effect is produced with the silver halides by light of practically all wave lengths to which the same halide is light sensitive. Like the photographic effect, it is influenced but little by extremely low temperatures and can be produced with light of practically the same intensity as is required to produce a developable effect.

The photographic reaction can take place in an exceedingly short

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Sheppard—Primary Process in the Formation of the Latent Photographic Image. Nature, **123** (1929), 979–980.

Toy—Mechanism of Formation of the Latent Photographic Image. Nature, **120** (1927), 441.

Toy and Harrison—Photo-Conductance Phenomena in the Silver Halides, and the Latent Photographic Image. Proc. Roy. Soc., A **127** (1930), 613–628, 629–637.

Trivelli—Tentative Hypothesis of the Latent Image. J. Franklin Inst., **204** (1927), 649–662; **205**, 111–122.

Trivelli—Mechanism of Formation of the Latent Photographic Image. Nature, **120** (1927), 728.

Webb—Photographic Latent Image from Standpoint of Quantum Mechanics Model of Crystals. J. Opt. Soc. Amer., **26** (1936), 367. Phot. J., **77** (1937), 142.

Weigert—Micelle Theory of Photographic Latent Image. Proc. VIIIth Int. Congress of Phot., Dresden (1931), 43–53.

time, as is shown by the practical use of exposures of 1/1000 of a second and less. It has been shown by Toy that the photo-conductivity effect can be detected within 0.001 of a second after the illumination is applied and in all probability begins instantaneously with the illumination.

The Role of the Sensitizing Nuclei.—Until the discovery of the sensitivity centers and the general realization of the essentially disperse nature of the photographic emulsion, all theories of the latent image were based upon the action of light on a homogeneous grain of silver halide. The discovery of sensitizing nuclei consisting of either silver sulfide, or silver sulfide and colloid silver, has added to the problem of the latent image that of sensitivity. There is no longer any doubt of the existence of these sensitizing nuclei and but little doubt that they are composed of silver sulfide, or possibly, silver sulfide and colloid silver. How the nuclei promote sensitivity is another question which is not so clear.

First, it may be pointed out that the sensitizing nuclei cannot be regarded as centers of special sensitiveness, or the spectral sensitivity of an emulsion would be that of silver sulfide and not silver bromide, nor does it appear likely that they act as photocatalysts, accelerating the photochemical decomposition of the silver halide. If the sensitizing nuclei are not in themselves photosensitive, nor can they accelerate the photochemical decomposition of the silver halide, how then can their undeniable influence on the sensitivity of the grain be explained?

Photographic sensitivity implies developability, i.e., a grain is not sensitive unless it can be converted into silver by a developer. Now in order that a grain may be developable it must have somewhere on, or near, its surface a particle of silver above a certain minimum size. Sheppard is of the opinion that the sensitizing nuclei sensitize for *development* rather than exposure. In other words, the effect of the nuclei is not to facilitate the decomposition of the silver halide, but to concentrate the photochemically reduced atoms of silver about themselves so as to form a nucleus of metallic silver sufficiently large to render the grain developable.

It is suggested that these sensitizing nuclei cause in their immediate neighborhood, depending upon their size, more or less strain in the silver halide crystal, resulting in changes in the positions of the electrically charged atoms, or ions, of silver and bromine in the crystal, thus creating spheres of weakness which serve to concentrate the photo-effect around the sensitizing center. According to this theory, the sensitivity centers do not play an active part in exposure. Their role is regarded as being purely passive and a result of the deformation produced by their presence in the structure of the silver halide grain.

A chemical viewpoint of the action of the sensitizing nuclei has been suggested by Hickman. According to this hypothesis the silver sulfide nuclei serve as an absorber of the bromine set free by the action of light on the silver halide of the grain surrounding it. This bromine attacks the silver sulfide resulting in the formation of free silver so that the total amount of silver produced is considerably greater than would be formed simply by the action of light on the silver halide. While it may not be impossible for such a reaction to take place under the conditions which probably exist in the silver halide grain, in no investigation of the interaction of silver sulfide and bromine in the laboratory has the formation of silver been observed.

Still another hypothesis of the action of the sensitivity centers has been tentatively advanced by Trivelli. As the silver halides have been shown to be photoconductive, and there is some basis for the assumption that in the silver halide grain there may exist a certain amount of finely divided silver as well as silver sulfide, Trivelli suggests that when light falls on the grain, the greater photoconductivity of the sensitivity nuclei as compared with the halide produces a difference in electrical potential which results in the electrolytic deposition of silver in contact with the sensitivity center and thus assists in building up a particle of silver sufficiently large to render the grain developable.

Useful as these various pictures of the mechanism of the sensitivity nuclei may be as working hypothesis, much experimental work will have to be done before the true facts are established.[11]

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[11] Sheppard, *The Theory of Photographic Processes and Methods,* Chapter 3. *Photography as a Scientific Implement,* D. Van Nostrand Co., N. Y., 1923. Lüppo-Cramer, "History of Latent Image Theories," *Zeit. Wiss. Phot.,* 13 (1924), 91; (1925), 122, 216.

CHAPTER VII

PHOTOGRAPHIC SENSITOMETRY

Definition and Scope of Sensitometry.—One of the primary concerns of sensitometry is the measurement of sensitivity. However, an adequate measure of sensitivity cannot be obtained without reference to the other characteristics of a photographic material, hence sensitometry is more completely defined as the quantitative measurement of the response of photographic material to radiant energy.

Moreover, as the effect of exposure becomes apparent only after development, quantitative determinations of sensitivity must involve the measurement of development and its effect on sensitivity.

While formerly of interest only to the manufacturers of photographic materials and those engaged in research, sensitometric methods are now widely employed in the processing of photographic materials, particularly in the motion picture industry, and as time goes on there is little doubt that sensitometric methods will be used more and more in practical photography.

Sensitometric investigations provide a means of determining and expressing quantitatively:

1. The speed, or sensitivity, of a photographic material.
2. The degree of development secured under given conditions of development.
3. The time of development for a given degree of development.
4. The latitude, or exposure range, of a material.
5. Conditions governing the reproduction of tone in the photographic process.
6. Means of expressing relative contrast and the maximum contrast attainable with a given film or plate and conditions of development.

Reciprocity Effect.—Measurements of the response of a photographic material to light, or other forms of photochemically active radiation, are based fundamentally on the density (or amount of metallic silver) produced under given conditions of development, by an exposure which is measured in terms of the illumination acting on the sensitive material multiplied by the time which it is allowed to act.

Bunsen and Roscoe, as a result of their investigations on the darkening of silver chloride papers, established what is called the *reciprocity law,* according to which the photochemical effect (or blackening produced) is the product of time and intensity; time being a reciprocal of intensity, or vice versa. It was shown by Abney, however, that the photographic plate does not exactly obey the reciprocity law and that the effect produced by a given exposure depends upon the actual values of intensity and time and not simply on their product.

Following a series of investigations on the relation of time and intensity in photographic exposure, Schwarzschild suggested that the relation might be written as

$$E = It^p$$

where E stands for the effective exposure, or photographic effect: I and t for intensity and time, and p a constant which Schwarzschild thought to be independent of the actual light intensities and of the sensitive material.

Later work has shown that for each plate there is an optimum intensity of light which produces the greatest developable effect. The value of this optimum intensity depends chiefly on the speed of the plate or film. In the region of the optimum intensity, the reciprocity law is approximately followed; only at lower intensities does Schwarzschild's rule hold. It has also been shown that the maximum density developable for a given exposure depends upon the intensity of light acting, decreasing as this becomes less. Lastly, the magnitude of the reciprocity failure increases greatly as the emulsion speed, or sensitivity of the emulsion, decreases and is apparently greater with color-sensitive than with non-color-sensitive materials.

Closely connected with the failure of the reciprocity law is the "intermittency effect," discovered by Abney, who found that the photographic effect of an intermittent exposure is not equal to a continuous

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Jones and Huse—On the Relation between Time and Intensity in Photographic Exposure. J. Opt. Soc. Amer., **7** (1923), 1115.

Jones, Huse and Hall—Relation between Time and Intensity in Photographic Exposure. J. Opt. Soc. Amer., **12** (1926), 321–348.

Jones and Webb—Reciprocity Law Failure in Photographic Exposures. J. Soc. Mot. Pict. Eng., **23** (1934), 142–159.

Toy—Relation between Time and Intensity in Photographic Exposure. Brit. J. Phot., **73** (1926), 704.

exposure for the same time but differs by an amount which depends upon the degree of intermittency and the speed of the sensitive material.[1]

Recently it has been found that an intermittent exposure produces the same result as a continuous exposure of the same duration if the degrere of intermittency is above a certain critical level which *varies with the intensity level.*[2]

Exposure of the Material for Sensitometric Purposes.—If the response of a material to light or other forms of radiant energy is to be determined quantitatively, it is obviously necessary to provide (1) a means of producing a series of accurately known exposures and (2) development under measurable and standardized conditions.

The exposure of the material involves (1) the establishment of a standard light source of known intensity and spectral composition and (2) a means of producing a series of known exposures on the photographic material.

Light Sources.—Candles, and lamps burning liquid pentane, amyl-acetate and acetylene have been employed as standards, but standardized incandescent electric lamps are used almost exclusively at the present time. It is necessary to calibrate such lamps accurately for luminous intensity and spectral distribution (color temperature) in a testing laboratory. Inasmuch as both of these factors depend upon the temperature of the filament, which in turn depends on the current flowing through the lamp, it is necessary to control with a high degree of precision the electric supply from which the lamp is operated in order to maintain a suitable standard.

The spectral distribution of energy in the radiation emitted by in-

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[1] Abney, *Treatise on Photography,* p. 391.

[2] Webb, "The Relationship Between Reciprocity Law Failure and the Intermittency Effect in Photographic Exposure," *J. Opt. Soc. Amer.,* **23,** 157 (1933).

Davis and Gibson—Artificial Sunlight for Photographic Sensitometry. Proc. Seventh Int. Congress of Phot., London. 1928.

Davis and Neeland—Variation of Photographic Sensitivity with Different Light Sources. Bur. Standards J. Research, 7 (1931), 843–850.

Davis and Neeland—Variation of Photographic Sensitivity with Different Light Sources. J. Soc. Mot. Pict. Eng., **18** (1932), 732.

Mees and Sheppard—Investigations on Standard Light Sources. Phot. J., **50** (1910), 287; Brit. J. Phot., **57** (1910), 627.

Walsh—Standards of Light for Photographic Sensitometry. Phot. J., **65** (1925), 52.

Report of the Optical Society of America Committee. Unit of Photographic Intensity. J. Opt. Soc. Amer., **12** (1926), 567–586.

candescent electric lamps of the type suitable for use as standards is quite different from that of sunlight. Since the radiation from an incandescent standard lamp is relatively richer in the long-wave region, a blue-violet filter is required to secure radiation approximating that of noon sunlight. To attain a color temperature of 5400° K., the figure adopted as a standard for noon sunlight, with the highest precision, a liquid filter is required; however, for practical purposes dyed gelatin filters such as the Wratten No. 79, 78 or 78-AA are quite satisfactory.

Sensitometers.—Since exposure is defined as the product of the illumination on the photographic material (in candle meters) and the time (in seconds), or;

$$E = i \times t,$$

a series of exposures may be produced by varying either factor while keeping the other constant. A series of exposures produced by variation of the intensity acting on different portions of the photographic material is termed an *intensity scale;* a scale produced by varying the time of exposure is termed a *time scale.*

An intensity scale may be produced in a number of ways[3] but the only method in general use consists in reducing the illumination on the different portions of the film, or plate, through the interposition of screens of known absorbing power. Such screens following the suggestion of Goldberg[4] are made of pigmented gelatin or are photographic copies of such screens and are of two types: (1) the so-called "optical wedge," in which the light absorption increases continuously, and (2) "step tablets," in which the increase is discontinuous.

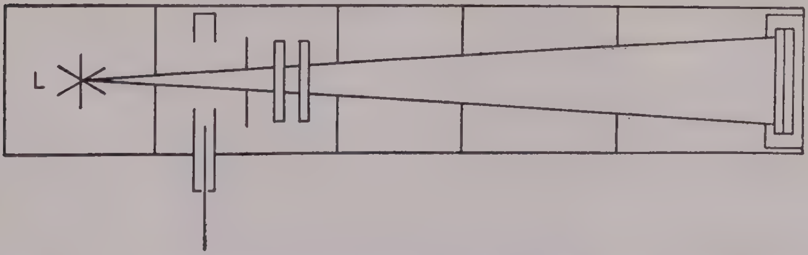

FIG. 123. Intensity Scale Sensitometer. Left to right, light source, sliding shutter filter, intensity scale and film. (Baines, *British Journal of Photography,* 1932.)

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[3] Jones, *Photographic Sensitometry.*

[4] Goldberg, *Brit. J. Phot.,* **57** (1910), 642, 648.

Since in practical photography, differences in exposure are the result of variations in the reflecting power of different parts of the subject, it is evident that an intensity scale approaches the conditions of practice more closely than does a time-scale. However, no simple, satisfactory means of producing intensity scales is known and the absorbing tablets used for this purpose are not sufficiently reproducible, permanent and free from selective absorption for sensitometric work of the highest precision. So far as permanency and freedom from selective absorption are concerned, photographic tablets appear the most satisfactory.

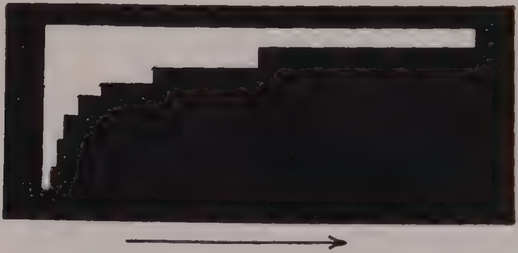

FIG. 124. Exposure Plate of Sensitometer

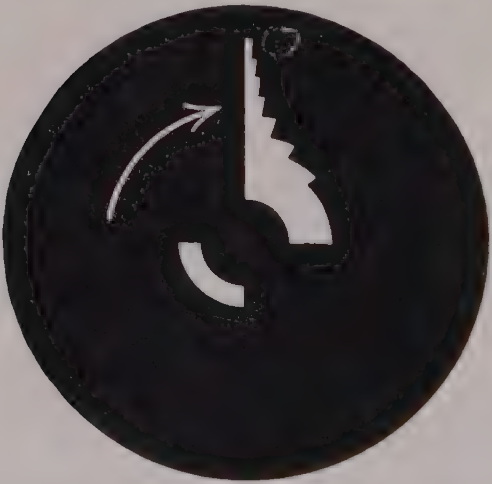

FIG. 125. Sector Wheel of the H. and D. Sensitometer

Time-Scales.—Time scales are produced by interposing between the light source and the photographic material a continuously moving opaque plate with a series of slits whose lengths vary in accordance with the exposures desired. The shutter may be rectangular with longitudinal slits moving in a straight line (Fig. 124) or angular openings in a circular disk (Fig. 125) which is rotated in front of the sensitive material. In Fig. 125 the shutter contains 9 apertures whose lengths increase logarithmically by consecutive powers of two. Thus the relative exposure for each aperture from the shortest to the longest is

Aperture	1	2	3	4	5	6	7	8	9
Relative exposure	1	2	4	8	16	32	64	128	256

In some cases, a series of exposures with a lower order of progression is desirable and this has led to the adoption in many sensitometers of a scale of exposures increasing as the power of the $\sqrt{2}$ or,

1 1.41 2 2.82 4 5.64 8 etc.

It is obvious that if a disk of the type shown in Fig. 125 is rotated an exposure time greater than that required for one revolution of the disk results in an intermittent exposure. In other words the total time of exposure for each aperture is the sum of the exposures produced with each revolution of the disk. The photographic effect of a series of intermittent exposures, however, is not the same as a continuous exposure of the same duration but varies with the length of exposure, the number of separate exposures, and the photographic material.

The errors resulting from an intermittent exposure may be avoided by rotating the disk more slowly so that the necessary exposures are obtained with a single revolution. If the time required for one revolution of the disk is relatively long a clutch may be used to engage the driving mechanism which rotates the disk at a constant speed throughout one revolution, at the completion of which the clutch is automatically disengaged and the disk is brought to a stop. This procedure

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Davis—Experimental Study of the Relation between Intermittent and Non-Intermittent Sector-Wheel Photographic Exposures. Bull. Bur. Stan. Scient. Papers, **21** (1926), 95–139.

Hardy—A Non-intermittent Sensitometer. Jl. Opt. Soc. Amer., **10** (1925), 149.

Higson—A Simple Non-intermittent Sensitometer. Phot. J., **60** (1920), 235.

Jones—A Non-Intermittent Sensitometer. Phot. J., **60** (1920), 60.

Rawling—Exposure Mechanisms. Phot. J., **65** (1925), 64.

Mees and Sheppard—Instruments for Sensitometric Investigation. Phot. J., **44** (1904), 200. (With excellent bibliography.)

is impractical if the time for one revolution is short, as it is difficult at a high speed to stop and start the disk, or to rotate it at a uniform speed. In this case, the disk is rotated continuously at the required speed and an electrically operated shutter is provided which is so controlled that it remains open for only one revolution of the disk.

No useful purpose would be served by a lengthy description of the different sensitometers based upon these general principles; instead, reference will be made to only one, the Eastman Sensitometer II-b, which is one of the best known and most widely used.

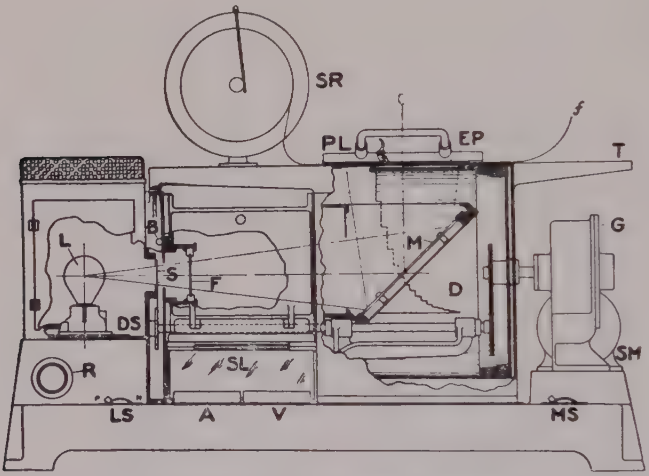

Fig. 126. Cross Section of the Eastman Sensitometer, Type IIb

The instrument is shown in detail in Fig. 126 which is a partial vertical section through the optical axis of the instrument.

L represents the standard lamp which is the source of illumination. A selectively absorbing filter *F* is placed in the path of the light coming from the lamp in order to modify its spectral composition to the desired quality. A plane mirror *M* reflects the light at right angles, thus illuminating the exposure plane *EP* in which the photographic material is placed. The rotating cylindrical shutter or drum *D*, having 21 exposure slots increasing in length by logarithmic steps from the shortest to the longest, controls the time factor of the exposure incident upon the adjacent steps of the exposure scale. The exposure plane is equipped with suitable guides so that two strips of 35 mm. motion picture film may be placed in position and exposed simultaneously. A platen *PL,* when pulled down, serves to hold these strips accurately in the exposure plane during exposure.

The drum is driven at a constant angular velocity by a synchronous motor *SM.* Through a reduction gear *G,* the motor turns the drum at 12 r.p.m. when operating on a 60 cycle line, or at 10 r.p.m., on a 50 cycle line.

When the machine is started by throwing the master switch *MS,* the drum revolves continuously. Exposures are made by means of the shutter *S,* operated by a one-turn mechanism. Upon pressure of the release button *B,* this shutter opens while the photographic material is protected from the exposing radiation by the opaque portion of the drum, and closes as soon as the slots in the drum have passed the exposing plane.

Developers and Development.—Since the effect of exposure becomes apparent only after development, it is evident that the response of a photographic material is in part dependent upon the conditions of development which must be standardized if accurate and reproducible results are to be obtained. In establishing standards for developers and conditions of development, consideration will naturally be given to the purpose for which the work is done. Since it is well known that many of the characteristics of an emulsion are profoundly modified by the constitution of the developer,[5] it is evident that if the work is done to supply information on the characteristics of material for practical purposes, the standards adopted must be those of practical photography; on the other hand if the object is to study the inherent differences in emulsions, to enable the manufacturer to maintain a

[5] Clark, *Phot. Jl.,* **65** (1925), 76.

Bloch and Horton—Mechanical Developing Appliance for Sensitometric Work. Phot. J., **68** (1928), 352–353.

Clark—Standard Development. Phot. J., **65** (1925), 76.

Davis and Neeland—Developers and Sensitivity. Bur. Stand. J. Res., 11 (1933), 379.

Harrison and Dobson—Note on the Uniform Development of Photographic Plates. Phot. J., **65** (1925), 89.

Sheppard—The Stability of pH of Standard Paraminophenol Developer. Proc. Ninth Int. Congress of Phot. Paris, 1935. S.&I.P. (II), **6** (1935), 400.

Sheppard and Crouch—Machine for the Automatic Development of Sensitometric Strips. Proc. Seventh Int. Congress of Phot., London. 1928.

Sheppard, Lambert and Atkins—Semi-Automatic Apparatus for the Development of Sensitometer Strips. Phot. Ind., **34** (1936), 988.

uniform product, or for the purpose of establishing a national or international standard of reproducibility; color of image, freedom from fog, sensitivity to changes in bromide and similar considerations alone need to be taken into account and these may result in the adoption of a developer and conditions of development quite different from those of practical photography.

The developer characteristics desirable in a standard developer for sensitometric work are:

1. *The deposit should be neutral;* i.e., non-selective absorbing.
2. *Freedom from fog* in the absence of an alkaline bromide or other restrainer.
3. *Energy sufficiently high* to produce good density, contrast, and speed.
4. *Relative insensitivity to an alkaline bromide* so that the results will not be affected appreciably by the presence of free bromide in the emulsion.
5. *Reproducibility:* i.e., freedom from unordered variations in the purity of the substances employed and conditions affecting the activity of the solution.

The Seventh International Congress of Photography recommended the following paramidophenol formula:[6]

p-aminophenol hydrochloride	7.25	g.
Sodium sulfite (anh.)	50.	g.
Sodium carbonate (anh.)	50.	g.
Water to make	1000.	c.c.

because of the grey (non-selective absorption) deposit, freedom from fog and its relative insensitivity to alkaline bromide so that the results are not materially affected by the presence of free bromide in the emulsion.

In the development of material for sensitometric purposes, efficient agitation of the developer is highly important in order that the developer-reaction products may be removed from the immediate vicinity of the film and distributed in the solution to prevent non-uniform development.

The methods developed to attain this end involve:

[6] Sheppard & Trivelli, *Proc. Seventh Int. Cong. of Phot.* (1928), p. 174.

1. In tanks:
    - *a. Mechanical rotation* of the exposures in the developing solution. It is difficult in this case to prevent directional development.
    - *b. Mechanical stirring* of the developer. The difficulty with this procedure is to insure that all parts of the solution will receive the same agitation.
    - *c. Plungers* moving up and down near the surface of the film to create a rapid and highly uniform distribution of the developer over the surface of the film.
2. In trays:
    - *a. Hand rocking.* This is fairly satisfactory if vigorous and irregular.
    - *b. Mechanical rocking.* Generally unsatisfactory as the action is too regular.
    - *c. Roller charged with developer.* The objection to this method is the rapid oxidation of the developer.
    - *d. Brushing* the surface of the film with a soft camel's hair brush. This is probably the best so far as uniformity in development is concerned.[7]

The temperature of the developing solution affects not only the rate of development but to a certain extent the speed and possibly other characteristics of the emulsion. The effect is more marked with some developers than others but necessitates in any case the use of a water-jacket, the temperature of which is maintained by means of a thermostat which should be accurate to 0.1° C.

Following development the sensitometer exposures are rinsed in a stop bath of dilute acetic acid to prevent further development and then transferred to the fixing bath. No special precautions are necessary in fixing or washing, but as the density of a photographic deposit depends in part upon the rate at which it is dried, the strips are usually dried in a drying cabinet at a constant relative humidity or by means of alcohol. Alcohol, however, cannot be used for drying acetate film with safety because the base is attacked, nor should a solution containing more than 80 per cent industrial alcohol be used or the gelatin may be rendered milky.

The Measurement of Density.—After exposure and development, the next step is to determine the response of the sensitive material to the different exposures. When a photographic material is exposed to light, or other form of radiant energy, some of the grains of silver halide are rendered developable, and upon development these are reduced to metallic silver. It is evident, therefore, that the amount of silver produced by a given exposure and conditions of development is a measure of the response of the sensitive material. It is also obvious that ordinary analytical methods of analysis would not only be inconvenient but subject to large errors on account of the relatively small quantities of metallic silver involved. Furthermore, such determinations would not provide any real information on the optical properties of the developed image. The relationship existing between the amount of the photo-chemical product (silver) produced by a given exposure under fixed conditions of development and its light-absorbing and transmitting properties was first expressed quantitatively by Hurter and Driffield.[8]

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[7] General summary of developing methods: Clark, *Phot. Jl.*, **65** (1925), 76; Crabtree, *J. Soc. Motion Pict. Eng.*, **25** (1935), 512.

They defined as the *opacity* of the deposit, the ratio of the incident to the emerging light; as *transparency,* the reciprocal of this, or the fraction of the incident light transmitted; and as *density* the logarithm of the opacity, or the negative logarithm of the transparency. Thus in the case of a silver deposit transmitting one-half of the incident light, the transparency is ½, the opacity 2 and density the common logarithm of this or 0.3.

Density, as thus defined is proportional to the mass of silver per unit area, or $D = pm$, where D is the density, m the mass of silver and p a constant termed the *photometric constant.*

The value of this constant varies to some extent with the developer and conditions of development.[9]

Densitometers.—Photometers designed particularly for the measurement of photographic densities are termed densitometers. They may be divided into two classes according to whether they measure the density directly or by comparison with a known density. All densitometers are alike in that they provide means for reducing the intensity of a standard light in a known manner, to match with a similar beam of light which has passed through the density to be measured.

The intensity of the comparison light may be reduced in a known manner by several methods, as for instance (1) by varying the distance of the light, (2) by the use of adjustable rotating sectors, (3) by polarization and (4) by the use of absorbing material such as the optical wedges mentioned previously (page 181).

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[8] Hurter & Driffield, *J. Soc. Chem. Ind.*

[9] Medinger, *Z. physik. Chem.*, **114** (1924), p. 89; Sheppard & Ballard, *J. Frank. Inst.*, **205** (1928), 659; *Phot. Jl.*, **66** (1926), 470.

The densitometer employed by Hurter and Driffield in their classical investigations was an instrument of the first class; the well-known bench photometer is based on the law of inverse squares, in which two beams are brought together for comparison on a grease spot. Densitometers with rotating sectors were used by Abney and more recently by Jones. The most widely used instruments, however, have been those employing polarization, and of these the most popular are the Hüfner and the Martens.

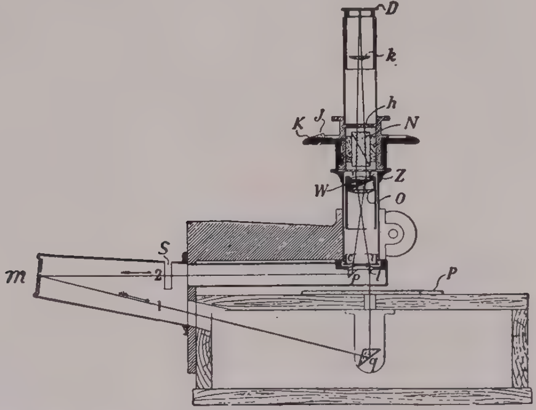

Fig. 127. Path of Light Rays in Marten's Densitometer

The construction of the Martens densitometer is shown in Fig. 127. One of the beams of light from an electric lamp placed at *M* proceeds, as shown by the arrow, to the totally reflecting prism *q*, whence it is reflected through the negative *p* and is rendered convergent by the lens *l* passing through the aperture *i* into the actual photometer head. It then passes through the Wollaston prism *W*, and the bi-prism *Z*, then through the Nicol *N* and through the converging lenses *h* and *k* to the eye placed at *D*. The other beam proceeds to the total reflecting prism *p*, thence through the Wollaston prism, the bi-prism, the Nicol, and reaches the eye at *D*. Thus there is produced at *D* two contiguous

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Davies and Owen—A Visual Photometer for the Measurements of Transmission and Reflection Densities. Phot. J., 75 (1935), 128.

Davies—Electrical Measurements of Reflection Density. Phot. J., 72 (1932), 57, 118.

fields, one formed by the beam of light which has passed through the density; the other, the comparison beam. The intensity of the latter can be reduced by the rotation of the Nicol *N* and the densities determined from the angle of rotation required to produce equality in the two fields.

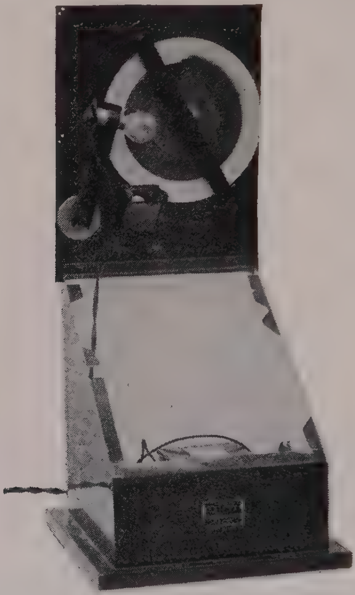

FIG. 128. Eastman Densitometer, Open to Show Construction

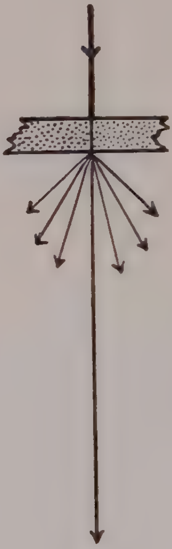

FIG. 129 Scatter of Light in Photographic Density.

Densitometers of class 4 employing calibrated optical wedges are more properly termed density comparators, for their measurement of density consists simply in comparing it with a known density. A number of densitometers of this type are available commercially;[10] the best known in this country is the Eastman Densitometer (Fig. 128).

[10] The Sanger-Shepherd Density Meter, manufactured by the E. S. S. Color Filter Co., London; The Densitometer Filmograph, made by the Etablishments Filmograph, Montrouge, France; Hilger Densitometer, Adam Hilger; Goldberg Densograph, Schmidt and Haenisch, Munich.

FERGUSON—The Ferguson Density Meter No. V. Phot. J., **64** (1924), 30; Brit. J. Phot., **71** (1924), 19.

Optical Characteristics of the Photographic Image.—Certain factors affecting density values as determined by densitometric measurement will now be considered.

In the first place, it may be noted that the photographic image consists of grains of metallic silver imbedded in gelatin. These not only absorb light but scatter a portion of that which is transmitted. Therefore, if the deposit is illuminated by specular (parallel) light (Fig. 129), the amount of light transmitted, and therefore the density as determined by densitometric measurements, will depend upon whether this scattered light is included in the measurement of the density or only the direct, undeviated light. The value of density as obtained with parallel light is termed *D* parallel or (D||) and that obtained when the scattered light is included is termed D diffuse, or (D⋇). The difference in the two values depends on the optical means employed in measuring the two densities and the light-scattering properties of the image, which in turn depends upon the emulsion and the manner of processing.

In contact printing, both the scattered and undeviated light reach the positive material; hence the effective density for contact printing is approximately equivalent to the diffuse density (D⋇). In projection printing, the lens is at some distance from the image and for this reason cannot collect and transmit all of the scattered light. It is evident, therefore, that in projection the effective density lies between D|| and D⋇. While in general, it is closer to the latter than the former, for practical purposes it is usually sufficient to determine the

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Ferguson and Read—A New Reflection Density Meter. Phot. J., **74** (1934), 249.

Goldberg—The Densograph. Brit. J. Phot., **57** (1910), 649; Eder's Jahrbuch, **24** (1910), 226.

Jones—A Densitometer for the Measurement of High Photographic Densities. J. Opt. Soc. Amer., **8** (1923), 231.

Mees and Sheppard—The Sensitometry of Photographic Plates. Phot. J., **44** (1904), 282 (with excellent bibliography).

Morrison and McFarlane—Eastman Transmission and Reflection Densitometer. J. Opt. Soc. Amer., **25** (1935), 417.

Sanger-Sheppard—Density Meter. Brit. J. Phot., **58** (1911), 926. British Patent 23,429 of 1911.

Toy and Rawling—Photo-electric Densitometer. Phot. J., **64** (1924), 189; Jl. Scient. Instr. 1 (1924), 362.

Tuttle—A Recording Physical Densitometer. J. Opt. Soc. Amer., **26** (1936), 282–292. Phot. J., **76** (1936), 495–504.

diffuse density by the use of a diffused source of illumination secured by placing the density to be measured in contact with opal glass.

If the silver deposit is free from selective absorption, the density values as measured visually are approximately equal to the effective printing density. This is generally true in the case of images developed in metol-hydroquinone, metol, paraminophenol or diaminophenol. In the case of pyro and other developing agents producing a stain image, the effective printing density is greater than the value obtained by visual measurement because of the difference in the spectral sensitivity of the eye and that of positive printing materials.

Since an unexposed portion of a sensitometric strip has a measurable density, termed the fog density, it is obvious that a certain fraction of each density is due to fog. The density due to fog, however, is not the same in the exposed steps as in the unexposed portion of the sensitometric strip. The relation between the fog density and the total density is a complicated one, but in general it may be said that as the total density increases, the fog density becomes less and less. This is due to the fact that the by-products released in the development of the exposed silver halide restrain the development of fog. Hence, in the higher densities the development of fog is restrained to a greater degree than in the lower.

It is the density due to the exposure, and not the total density, which

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BULL AND CARTWRIGHT—The Measurement of Photographic Density. Phot. J., **64** (1924), 180.

BULL AND CARTWRIGHT—An Evaluation of the Light Scattered by Photographic Densities. Phot. J., **65** (1925), 177.

CALLIER—Absorption and Scatter of Light by Photographic Negatives Measured by Means of Marten's Polarization Photometer. Phot. J., **49** (1909), 200; Zeit. wiss. Phot., **7** (1909), 257.

KOERNER AND TUTTLE—Experimental Determination of Photographic Density. Phot. J., **77** (1937), 444.

RENWICK—How Should the Densities of a Photographic Deposit be Measured. Brit. J. Phot., **71** (1924), 65.

TOY—The Standardization of Photographic Density Measurements. Phot. J., **65** (1925), 164.

TUTTLE—Densitometry and Photographic Printing, Illumination of the Negative and its Effect upon Density. J. Opt. Soc. Amer., **24** (1934), 272–278.

TUTTLE—Relation Between Diffuse and Specular Density. J. Opt. Soc. Amer., **12** (1926), 559–565.

TUTTLE—The Relation between Diffuse and Specular Density. J. Soc. Mot. Pict. Eng., **20** (1933), 228–235.

is the true measure of the response of the sensitive material; obviously then the measured densities should be corrected for fog.

However, since the fog density is not the same for all densities, the ncessary correction cannot be made by subtracting from each of a series of densities a uniform fog value as obtained from an unexposed portion of the strip. Despite the rather complex formulas devised for correcting measured densities for fog,[11] it is usually sufficient to employ densities as measured, neglecting any addition due to fog if the fog value is reasonably low.

The Density-Exposure Relation.—The relation between exposure and the response of the material, as shown by the density produced under given conditions of development, is usually presented in the form of a curve in which density is plotted against the logarithm of the exposure. Such a curve is shown in Fig. 130. As this method of expressing sensitometric data was developed by Hurter and Driffield, it is frequently referred to as the H & D curve; it is also termed the characteristic curve, or the *D*-log *E* curve. For the greater part of its length this curve is a straight line. Throughout this range of exposures, density is proportional to the logarithm of the exposure. In other words, for each increase in exposure there is a regular and uniform increase in density. (See Fig. 131.)

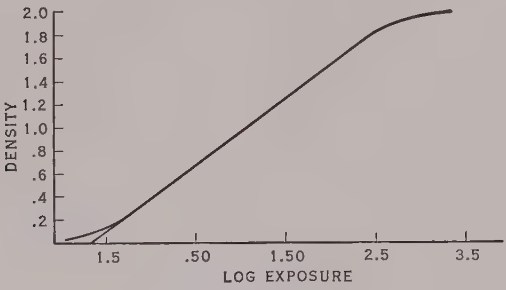

FIG. 130. The *D*-log *E* Curve

As density is the logarithm of the opacity, it is evident that the opacity is proportional to the exposure within the straight-line portion of the curve. This then is the region of correct exposure, for within

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[11] Medinger, *Z. physik. Chem.*, **114** (1924), 89; Wilsey, *Phot. Jl.*, **65** (1925), 454.

PRITCHARD—Fog Correction of Photographic Densities: A Sensitometric Study. Phot. J., 67 (1927), 447–459.

this exposure range, the opacities of a negative are proportional to the exposures produced by the corresponding brightnesses of the subject.

The lower portion of the curve is concave to the exposure axis; thus

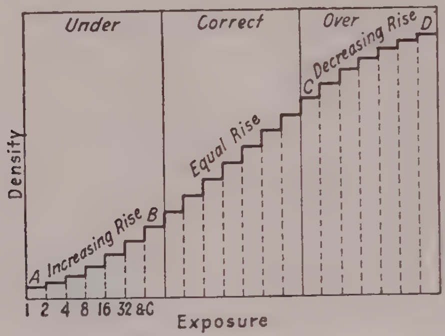

FIG. 131. Step Chart Illustrating Relation of Density and Exposure in the Three Portions of the D-log E Curve

within this exposure range there is no fixed relationship between density and log exposure but instead the increase in density for a given exposure difference increases with the exposure. (See Fig. 131.) This is the *period of underexposure.*

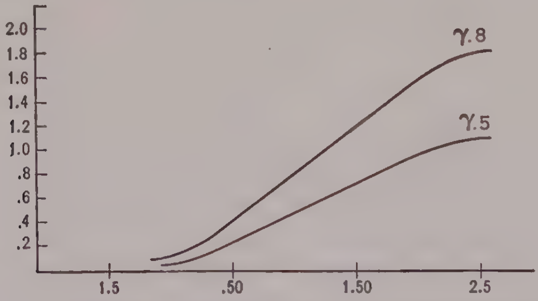

FIG. 132. Effect of Development on the Density Differences

The upper portion of the curve is convex to the exposure axis. In this portion also there is no fixed relationship between density and log exposure, but the increase in density for a given exposure difference decreases steadily as the exposure is increased, finally becoming zero. Beyond this point, increased exposure results in less density so that the result is a positive instead of a negative. This *period of reversal* is reached only with greatly increased exposure and so far as the vast majority of photographic materials is concerned is only of theoretical interest.

Effect of Development on the Density-Differences (Gamma).—Under given conditions of development increasing the time of development increases proportionally each density on the straight-line portion of the D log E curve (Fig. 132); therefore, while the density *ratios* remain unchanged, the density *differences* are increased. As the density differences increase, the gradient, or slope, of the straight-line portion, and consequently the angle between it and the log exposure axis, increases also. The tangent of this angle being a measure of the density differences, is therefore a measure of the degree of development. It was termed by Hurter and Driffield the *development factor* and designated by the Greek letter γ (gamma). Today it is usually refered to simply as gamma.

Gamma is thus the ratio of the difference between any two densities on the straight-line portion of the D log E curve and the difference in the logarithms of the corresponding exposures, or

$$\gamma = \frac{D_2 - D_1}{\text{Log } E_2 - \text{Log } E_1}\,.$$

When gamma is equal to 1, the density differences are proportional to the differences in the logarithms of the exposures which lie within the straight-line portion of the D log E curve. In a camera exposure these exposures are the direct result of differences in brightness; *hence* with development to a gamma of 1 the differences in density are proportional to the logarithm of the brightnesses of the corresponding parts of the subject. As density is the logarithm of the opacity, it follows that the ratio of the opacities is the same as that of the brightnesses which they represent. Development to a gamma of less than one results in the opacity differences being less than the brightness differences of the subject, while with development to a gamma greater than one, the opacity differences are also greater.

The opacity differences determine the contrast of the negative, therefore, gamma is proportional to contrast if both the maximum and minimum densities of the negative are within the straight-line portion of the curve. If, however, some portions of the subject are represented by densities outside the straight-line portion of the curve, then the contrast of the negative is not expressed by gamma.

Calculation of Gamma.—To determine the value of gamma from the D log E curve using the formula

$$\gamma = \frac{D_2 - D_1}{\log E_2 - \log E_1}$$

erect two perpendiculars from the exposure axis to the points of intersection with the straight-line portion of the curve. Determine the densities at the points of intersection and substitute the density and log exposure values in the equation.

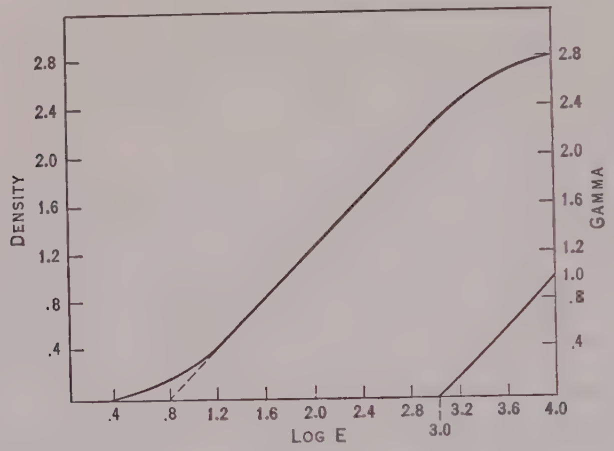

FIG. 133. Calculation of Gamma by the H. and D. Method

If, in Fig. 133, a line is drawn from the exposure axis at a log E value of 3.0 parallel to the straight line portion of the D log E curve, the angles of both with the exposure axis will obviously be equal since the lines are parallel. The tangents of the two angles are likewise equal and both are equal to gamma. Now, in the right angle triangle formed by the constructed line, the tangent of the angle is equal to the altitude divided by the base. The base, however, is equal to 1.0, since the difference in log units is 1.0. Consequently, if the right hand side of the chart is marked with a scale corresponding to the density scale on the left side, the point of intersection of the constructed line and the scale is equal to gamma.

In practice, gamma is usually determined by means of a transparent scale known as a *gammeter*. (Fig. 134.) If the arrow on the left side of the base line is placed on a point along the straight line portion of the *D* log *E* curve, with the base of the gammeter parallel to the log E axis, the point of intersection of the straight-line portion of the curve and the scale indicates the gamma.

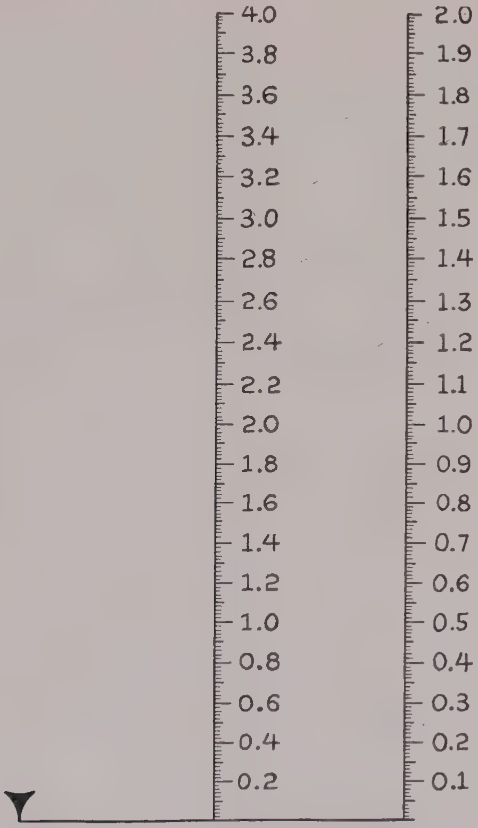

FIG. 134. One Form of Gammeter

The Time-Gamma Curve.—The relation between the time of development and gamma for a given photographic material, developer, and conditions of development can be determined by developing a number of sensitometer exposures for different times, determining the

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RENWICK—An Instrument for the Measurement of Gamma. Phot. J., 54 (1914), 163.

WHITE—Gamma by Least Squares. J. Soc. Mot. Pict. Eng., 18 (1932), 584.

value of gamma for each time of development and plotting gamma against the time of development.

In Fig. 135, for example, are five D log E curves for a well-known film developed 2, 4, 6, 8 and 10 minutes. Plotting gamma against the corresponding times of development results in a *time-gamma curve* (Fig. 136). From this curve the time of development under the same conditions for any desired gamma is obtained by extending a line from the desired gamma, parallel with the time of development scale, to the point of intersection with the time-gamma curve. A line from this

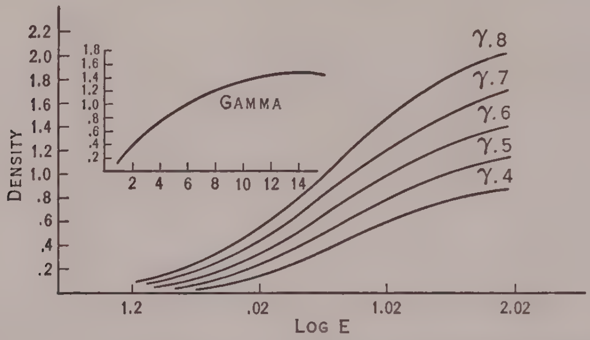

Fig. 135. H. and D. Curves Showing the Variation with the Time of Development

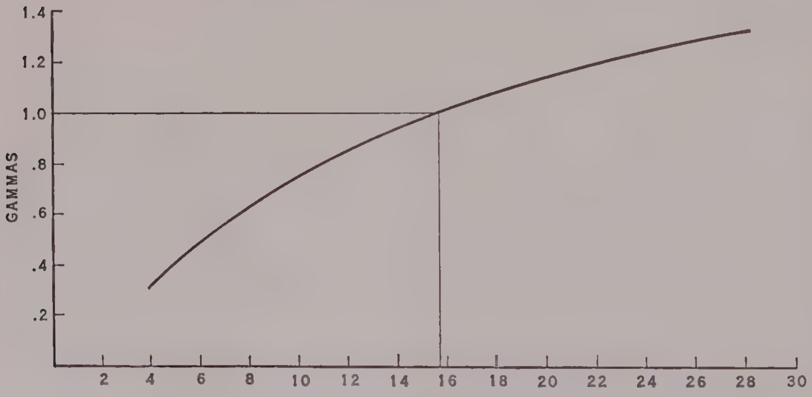

Fig. 136. Determining Time of Development for Required Gamma

point, perpendicular to the base, cuts the time of development scale at the corresponding time of development.

By reversing the procedure, the gamma produced by a given time of development may be found.

It should be noted, however, that these values are without practical significance unless the conditions of development are exactly duplicated. Values obtained, for instance, from tray development cannot be directly applied to tank development, nor can results obtained with a fresh developer at a given temperature be applied to a used developer, nor to another film.

The variation in the time of development possible for a given tolerance in gamma is termed the *processing latitude.* If, for example, a gamma of 0.5 must be maintained within a tolerance of plus or minus 0.04, the permissible variation in the time of development may be found by drawing lines from the two gamma values, namely 0.46 and 0.54 (Fig. 137), to their intersection with the time-gamma curve and dropping perpendiculars from these points of intersection to the time of development scale. The difference in the two times of development thus found constitutes the *processing latitude.* For any given conditions of film and developer, the processing latitude increases with the degree of development, or gamma. Processing latitude is a very important characteristic when sensitive materials must be developed to certain prescribed gammas, as in the processing of motion picture sound records.

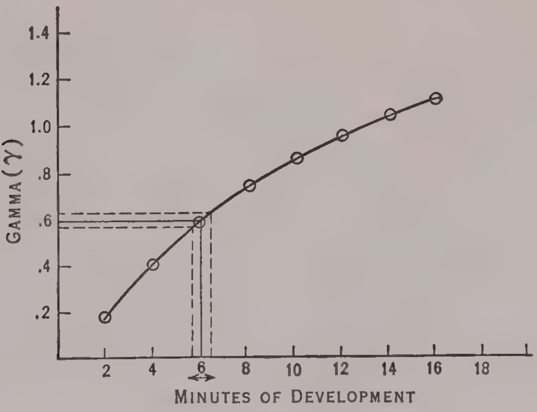

FIG. 137. Processing Latitude

Gamma Infinity.—The amount of contrast, and therefore the value of gamma, since gamma is the numerical expression of contrast, increases with the time of development up to a certain point; beyond this point no further increase occurs, in fact, after this stage has been reached, lengthened development *reduces* rather than increases the value of gamma owing to the intervention of fog, the effect of which is greater on the lower densities than on the higher. The maximum amount of contrast or, in other words, the highest gamma obtainable with any given material is termed *gamma infinity* (γ_∞).

The value of gamma infinity depends chiefly upon the sensitive material, although experimentally small variations are secured with different developing agents.[12] High speed emulsions for portrait work have a low gamma infinity as a high degree of contrast is never required in portrait work: in fact material tending to give a high gamma would be a disadvantage. In commercial, landscape and general exterior work greater contrast is required and sensitive materials made for these purposes are made to develop to higher values of gamma infinity than those made for portrait work. The greatest contrast of all is secured with plates of the process type as used for copying line work in black and white where absolutely clear lines together with a field of the greatest possible opacity is required.

Gamma infinity may be determined experimentally, but as it involves the measurement of very high densities and since these may be more or less affected by the fog produced on long development, the process is subject to large experimental errors and the values of gamma infinity are generally determined by calculation from lower values of gamma. It will be remembered that in exposing the sensitive material in the sensitometer two strips were exposed under identical conditions and that these strips were later developed under like conditions, the duration of development, however, varying as 1:2.

A method of calculating gamma infinity from the values of two sensitometric strips developed so that

$$t_2 = 2t_1$$

was first worked out by Mees and Sheppard in 1903.[13] From certain mathematical data based upon the velocity of development they calculated the following expression of gamma infinity in terms of lower gamma:

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[12] Nietz, *Theory of Development,* p. 102.

[13] *Phot. Jl.,* 43 (1903), 199.

$$\gamma_\infty = \frac{\gamma_1}{1 - e^{-kt}} = \frac{\gamma_2}{1 - e^{-kt_2}}.$$

This formula, however, is not so simple as that of Renwick:[14]

$$\gamma_\infty = \frac{(\gamma_1)^2}{(2\gamma_1) - \gamma_2}.$$

A graphical method of determining gamma infinity which avoids all calculation worked out and published by Renwick will be found extremely convenient.[15]

The Measurement of Sensitivity or Speed.—The measurement of sensitivity, or speed, is a very important part of sensitometry; in fact, some methods of sensitometry are concerned wholly with the measurement of this characteristic. Four criteria have been used to measure the sensitivity of photographic materials:

1. *The exposure required to produce the least perceptible density.* (Threshold value.)
2. *The exposure required to produce a certain density above fog.* (The DIN system.)
3. *The exposure obtained by the projection of the straight-line portion of the D-log E curve to the log E axis.* (The *inertia* of Hurter and Driffield.)

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[14] *Phot. Jl.*, 51 (1911), 213.

[15] *Phot. Jl.*, 63 (1923), 331. For two other methods see: Renwick, *Phot. Jl.*, 54 (1914), 165–6. Krohn, *Phot. Jl.*, 54 (1914), 166–7.

Davis and Neeland—Experimental Study of Several Methods of Representing Photographic Sensitivity. Bur. Stand. J. Res., **7** (1931), 495–517.

Davis and Neeland—Methods of Denoting Sensitivity. J. Opt. Soc. Amer., **21** (1931), 416. S.&I.P. (II), **2** (1931), 334.

Formstecher—Proposals for a Practical Index of Speed. Phot. Ind. (1926), 1146.

Luther—Interpretation of the Characteristic Curve. Phot. J., **65** (1925), 185.

Thorne-Baker—Interpretation of the Characteristic Curve. Phot. J., **65** (1925), 181.

Mees and Sheppard—On the Highest Development Factor Obtainable on any Plate. Phot. J., **43** (1903), 199.

Renwick—An Improved Method of Computing the Velocity Constant and Gamma Infinity. Phot. J., **63** (1923), 331.

Toy and Higson—Factors Determining Gamma Infinity. Phot. J., **63** (1923), 68; S.&I.P., **3** (1923), 131.

4. *The exposure at the point on the D-log E curve representing the minimum useful density difference.* (The minimum gradient method of Jones, Russell and others.)

Threshold Speed.—This is found by impressing on the light-sensitive material a series of known exposures, developing under standardized conditions, and determining the exposure producing the least perceptible deposit of silver when placed face down on a sheet of white paper. The sensitivity of the material is then expressed by a number proportional to the reciprocal of the exposure required to produce the faintest visible deposit.

The best known method of measurement based upon threshold values is that due to Scheiner (1894). The Scheiner number was obtained originally by exposing the sensitive material in a rotating disk sensitometer, having an exposure range of 1 to 100 divided into 20 equal steps numbered from 1 to 20, developing under certain prescribed conditions, and expressing speed by the number of the step producing the threshold density. The ratio of exposures between consecutive steps on the Scheiner sensitometer is as 1 : 1.27; hence the relative speed as represented by any given Scheiner number is 1.27 greater than the next lower.

In time, various modifications were made in the original method so that no reliance could be placed in the Scheiner speed number and in 1931 it was officially superseded in Germany, the land of its origin, by the DIN method.

There are several objections to the use of the threshold exposure as a means of evaluating the speed of a sensitive material. In the first place, the threshold exposure is not a constant, but depends upon the conditions under which the developed sensitometer strip is examined and the conditions of development.[16]

Much more serious, however, is the fact that the threshold exposure is not a true index of the speed of a photographic material. From the standpoint of practice, the speed of a sensitive material is measured, not by the exposure required to produce a trace of an image, but by that required to produce an image whose density differences more or less satisfactorily represent the brightness differences of the subject photographed. As there is no fixed relationship between the threshold exposure and that required for satisfactory rendering of the gradations of the subject the threshold exposure is not an adequate means of measuring the effective speed of a photographic material.

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[16] "Variations in the Threshold Speed of an Emulsion According to the Developer and Conditions of Development," Bullock, *Science et Industries Photographiques* (1926), 33; (1927), 5; (1929), 24.

The DIN Method of Measuring Sensitivity.—In 1931 the manufacturers of photographic materials in Germany adopted a method of determining speed which is termed the DIN method; the letters DIN being a contraction of "Das ist Normal."

In this method the sensitive material is exposed in a special sensitometer employing an intensity scale of thirty steps, ranging in density from 0 to 3.0, the density increment of each step being 0.1. The light source is a standardized 40 watt incandescent lamp which is used with a filter to produce a daylight standard. The exposure of 1/20 second is made by means of a drop shutter.

After exposure, the sensitometer strip is developed in a specified metol hydroquinone developer. In view of the fact that there is no prescribed time of development, the time for any particular sensitive material is determined after preliminary tests have revealed the development time which results in optimum rendering of the lower densities.

The speed of the material is determined from the step having a density of 0.1 greater than fog, rather than the lowest perceptible density as in the threshold method. This particular step is found by measuring the densities in a special comparison densitometer in which one of the comparison beams passes through the fog strip and the other, the exposed portion of the sensitometric strip. A supplementary density of 0.1 is placed in the comparison beam which passes through the fog density so that it is increased automatically by 0.1. When the photometric field is uniformly illuminated, the density of the exposed area is thus 0.1 greater than fog. The density of the corresponding step on the sensitometer step wedge is then determined. This density multiplied by 10 constitutes the DIN speed.

DIN speed numbers are, therefore, inversely proportional to the common logarithm of the required exposure, and an increase of three units in the speed number means that the required exposure is one-half.

As yet, the DIN system has found no application outside of Ger-

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HANSEN—Relation between Scheiner and DIN Sensitivities. Brit. J. Phot., **82** (1935), 131.

BILTZ AND EGGERT—Connection between DIN and Scheiner Values. Phot. Ind., **32** (1934), 1296.

LUTHER—The Sensitometric Method "DIN 4512." Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 260.

many. The method has been rather seriously criticized in other countries, particularly the specifications relating to development. These, it is argued, are not comparable to those employed in practice. The specifications for development result, with some materials, in a degree of development in excess of that which would be given in practice. This would not be a serious matter if the ratio of the speed for the so-termed "Optimum Development" to that at normal development were the same for all materials. Experimental evidence available at the present time indicates that there is a fairly constant ratio for ordinary roll film, but that considerable variation exists with other types of sensitive material. In this case, it would be possible for two materials having the same DIN speed number to show considerable differences in effective speed when developed to the same degree of contrast. However, it is not possible to express the speed in terms of contrast (or gamma) since there are certain sensitive materials which increase considerably in speed as development progresses, but, beyond a certain point, show only slight increase in contrast. It is not too much to state, therefore, that in its present form the DIN system is not likely to be adopted as a universal standard.[17]

H & D Speeds.—When the straight line portion of the characteristic curve is extended to intersect the log-E base, an exposure is indicated which was termed by Hurter and Driffield the *inertia*. The inertia is an inverse measure of speed so that a material of high speed has a low inertia and vice-versa. It is necessary, therefore, to take the reciprocal of the inertia in order to obtain numbers which are directly proportional to the speed of the sensitive material. However, since the reciprocal of the inertia is in some cases less than unity, it is customary to multiply the reciprocal by a constant so as to obtain more convenient numbers. Present American practice is to multiply the reciprocal value by 10. The H & D speed in this case is represented by

$$S = \frac{10}{\text{Inertia}}\,.$$

Hurter and Driffield used a factor of 34 and still other values have been employed.[18]

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[17] "The DIN Speed-Marking for Plates and Films," Ferguson, *British Journal of Photography*, **81**, June 29, 1934, p. 380; "International Standardization of Speed Numbers," *British Journal of Photography*, **82**, August 2, 1935, p. 483; Jones, *Photographic Sensitometry*, pp. 63–95; Jacobsen, *American Annual of Photography*, 1937, p.   ; Clark, *American Annual of Photography*, 1937, p.   .

[18] For the origin of the factor of 34 see Ferguson, *Phot. Jl.*, **66** (1926), 514.

The inertia was selected by Hurter and Driffield as a means of expressing speed because, with the photographic materials then available (1890), it was a characteristic of the material which was not affected by variation in the time of development (provided the developing solution does not contain a soluble bromide) ; the developing agent (except for a few agents of low reduction potential) ; or the composition of the developing solution. If a bromide is added to the developer, or if the emulsion contains free bromide (the vast majority of negative emulsions now contain free bromide), the inertia is not constant for different times of development, but shifts to the left as the degree of development, of gamma, increases (Fig. 138). It is obvious that under these conditions the speed of the material, as determined from the inertia, varies with the degree of development and that for each time of development, or gamma, there is a corresponding H & D speed.

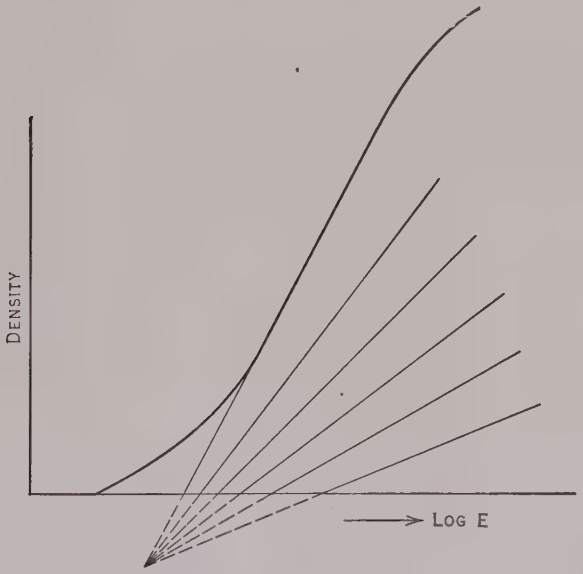

FIG. 138. Effect of Soluble Bromide in Development on Inertia Values

Still other complications arise in expressing the speed of photo-

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BAKER—Interpretation of the Characteristic Curve. Phot. J., **65** (1925), 181.

BLOCH—Interpretation of Results. Phot. J., **65** (1925), 186.

DAVIS AND NEELAND—Variation of Photographic Sensitivity with Development Time. J. Soc. Mot. Pict. Eng., **18** (1932), 742.

graphic materials by the inertia. In some cases, the material does not produce a satisfactory straight-line relationship between density and log exposure, or there may be two more or less well defined straight-line portions. In such cases it is difficult to find the true inertia. There is likewise a wide divergence in the shape and position of the curve with different times of development, especially among materials of high sensitivity.

Finally speed, as determined from the inertia, ignores the toe portion of the *D*-log *E* curve. However, the development of photographic materials with an extended toe portion has brought about the very general use of some of this portion of the curve in practical photography. Experience has shown that, within certain limits, it is possible to do this and still obtain acceptable, if not strictly accurate, tone reproduction. Under such conditions the inertia does not represent the effective speed of the material.

The two characteristic curves in Fig. 139 represent two emulsions having the same H & D speed. They differ widely, however, in the toe portions and in that range the corresponding densities and likewise the density differences are greater in the material represented in the upper curve than in the lower. In one case the density difference may be practically useless; in the other the same exposures may produce a printable difference in density. Thus, while the speeds of the two materials as determined from the inertia are the same, in practice their speeds are quite different. In recent years, therefore, efforts have been

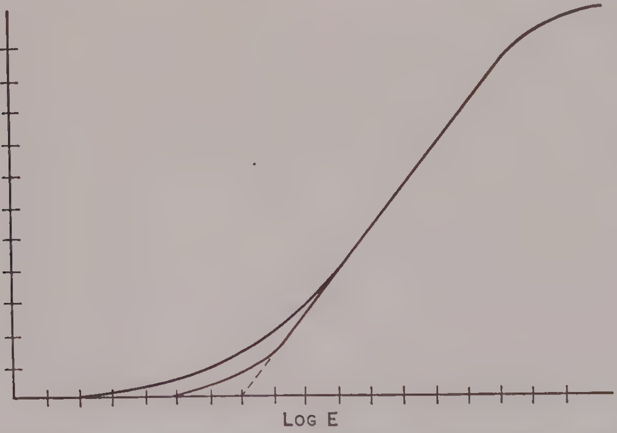

Fig. 139. Limitation of the Inertia as a Measure of Practical Speed

made to develop methods which more adequately express the speed of a photographic material from the standpoint of practical usage.

Determination of Speed from the Minimum Useful Gradient.—In practice, the speed of a photographic material is determined by the exposure required to reproduce the differences in brightness in the shadow portions of the subject by differences in density which are sufficient to result in satisfactory tone rendering in the print. The speed of a photographic material, therefore, cannot be expressed in terms of the exposure for any particular density but in terms of the exposure required to produce a suitable *difference in density.*

Differences in density determine the slope, or as it is called the gradient, of the D-log E curve. The maximum gradient is attained in the straight-line portion and throughout this exposure range the gradient is constant. There is no fixed gradient within the toe portion of the curve and the gradient grows less and less as the densities decrease. The point on the D-log E curve at which the density differences, or gradient, is just sufficient to produce acceptable tone reproduction in the print is known as the *minimum useful gradient.* The density difference corresponding to the minimum useful gradient is not fixed but depends upon the contrast range of the negative as a whole and is conveniently expressed as a fraction of the maximum gradient, or gamma. The work of Luther, Jones and Russell and others indicates that, in the majority of cases, the minimum useful gradient is approximately one-half that of the maximum gradient, or gamma.

The proposal to use the exposure required to produce the minimum useful gradient as a means of evaluating speed has been widely discussed in recent years. Jones and Russell have designed a gradient densitometer for rapidly and accurately determining directly from a sensitometric strip which has received a continuous exposure (i.e., not stepped) the point at which the gradient is one-half that of the maximum gradient or gamma.

It is not improbable that some method of determining speed based

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Jones and Russell—Minimum Useful Gradient as a Criterion of Speed. Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 325. Phot. J., **75** (1935), 657.

Jones and Russell—Minimum Useful Gradient as a Criterion of Photographic Speed. *Phot. Jl.*, **75** (1935), 657.

Romer, Markocki and Biernat—Numerical Expression of Speed Based on Relative Minimum Gradients. Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 265.

upon the *minimum useful gradient* will find general acceptance within the next few years.

Latitude.—The latitude, or exposure scale, of a photographic material is strictly defined as the difference in exposure units over which correct proportional reproduction is obtained; i.e., the straight-line portion of the D-log E curve. Thus if from the extremities of the straight-line portion of the curve (Fig. 140) perpendiculars are dropped to the log E axis, the difference in exposure units at the points of intersection represents the latitude, or exposure scale, of the material.

The latitude of a sensitive material as determined in this manner is not a constant of the emulsion but varies with the degree of development, or gamma. As the latter increases, the projection of the straight-line portion of the D-log E curve on the exposure axis decreases (Fig. 140) and consequently the latitude becomes less. Likewise, sensitive materials normally used at a high gamma, such as positive or process films, have a short exposure scale, or latitude.

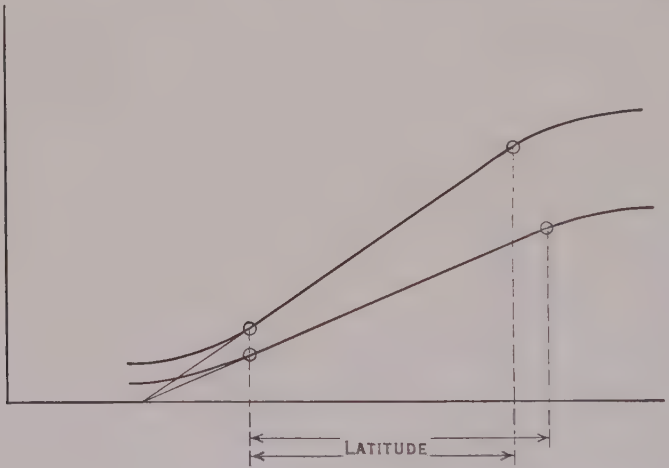

FIG. 140. Exposure Scale or Latitude

In practice, the latitude of a sensitive material is greater than that indicated by the projection of the straight-line portion of the D-log E curve on the exposure axis, since it is usually possible to use a portion of the curve at both extremities of the straight-line portion, without serious loss in quality of tone reproduction.

The latitude, or exposure scale, is a very important characteristic of a photographic material, as it indicates the range of brightnesses which can be acceptably recorded in the negative and hence, in a large measure, the purposes for which the film or plate is suitable. Fortunately, the actual exposure scale of most good negative materials is greater than the range of brightnesses in the vast majority of the subjects photographed. Exceptions, of course, occur, but in general the range of brightnesses in ordinary subjects is about 1–30, or less, and only in exceptional cases does it exceed 1–100, while the exposure scale of a good negative material is usually not less than 1–200 and is frequently considerably more. The exposure scale of positive materials is much less and in general the higher the gamma to which the material is ordinarily developed, the lower is its latitude.

The greater the latitude of a sensitive material, the greater is its *tolerance in exposure*. For any given photographic material, the greater the range of brightnesses in the subject, the less the tolerance in exposure.

Spectral Sensitivity.—The variation in the response of a photographic material with the wave length of the radiation to which it is exposed constitutes what is termed *spectral sensitivity* or frequently *color sensitivity*. The spectral sensitivity of a photographic material is a very important characteristic as it determines to a large extent the tones in which colored objects are rendered.

The determination of spectral sensitivity involves the isolation of comparatively narrow bands of the spectrum and determining, by one of several methods, the response of the film or plate to radiation within these spectral regions. The most accurate methods of making such measurements require a *monochromatic* sensitometer which consists [19] essentially of a spectrograph, a means of isolating any desired portion of the spectrum, and a sensitometer.

Sensitometer exposures are made with this instrument in the usual manner, but using monochromatic light instead of white light. From the data accumulated as a result of measurements throughout the spectrum, a spectral sensitivity curve showing the relation between wave length and sensitivity may be plotted. Spectrographic methods of this character, while necessary for a complete analysis of the spectral sensitivity of a film or plate, are lengthy, laborious, and exacting; furthermore the results obtained by simpler methods are adequate for most purposes.

One of the most widely used methods of comparing the spectral-sensitivity characteristics of different photographic materials is by means of wedge spectrograms. These are made on a special type of spectrograph whose essential features are shown in Fig. 141. A spectrum of the light source at the extreme right is formed on the sensitive material, placed at the back of the camera to the left, by means of a diffraction grating and the optical system shown. A blackglass

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[19] Jones, *Photographic Sensitometry.*

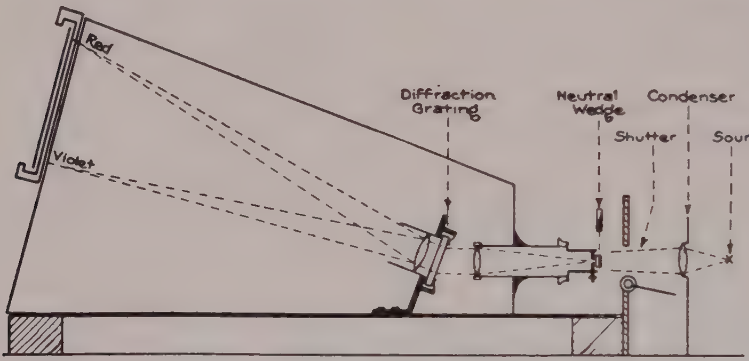

FIG. 141. Cross Section of Wedge Spectrograph

wedge placed directly in front of the slit varies the illumination across the spectrum logarithmically, so that the height of the exposed portion of the material at any point indicates the logarithm of the sensitivity at that particular wave length.

Two facts must be kept constantly in mind when using wedge spectrograms as a means of estimating the spectral sensitivity characteristics of a particular film or plate: (1) the curve represents the relation between sensitivity and wave length only in terms of the light source used for the exposure; (2) the absorption of the glass wedge is greater for the short wave region than for the remainder of the spectrum, so that the sensitivity of the film or plate to blue-violet is relatively greater than wedge spectrograms would indicate. This difficulty may be avoided by using rotating sectors in place of an optical wedge; however, it is not serious if wedge spectrograms are used simply for comparing different materials.

A third method consists in determining the response of the material to certain selected regions of the spectrum as isolated by filters. The red, green, and blue tricolor sets are frequently used for this purpose. The relative exposure required with each of the three filters to produce the same result as on a clear strip is determined and expressed as the *filter factor.* The factor thus represents the number of times the exposure for each filter must be multiplied to produce the same effect as a given exposure on the clear strip. This method is identical with that used in determining filter factors.

Color charts, prepared by three-color printing or with pigments, are often recommended as a means of determining spectral sensitivity. The use of these is not advised as the colors obtained in this manner are impure and reflect appreciable amounts of light from all parts of the spectrum so that the results obtained are inconclusive.

CHAPTER VIII

THE PHOTOGRAPHIC REPRODUCTION OF TONE

A photograph may be made either for the purpose (1) of producing an image which will excite in the mind of the observer the same sensation as that produced by the original or (2) of conveying a certain impression which is desired for its artistic effect. Since photography is essentially a factual method of reproduction, it is probable that in the larger number of cases the first of these is the primary, if not the sole, objective. The extent to which this is possible depends upon the ability of the photographic process to reproduce the brightness of each elementary area in the object. A careful analysis of the various processes involved, as well as an analysis of those factors upon which depends the operation of our visual perception, is obviously essential in the determination of the faithfulness of tone rendition under any given set of conditions.

The visual impression produced by any subject depends upon a number of factors, among which the most important are physical brightness, brightness difference or contrast, and hue. So far as the ordinary processes of photography are concerned, the first two are by far the more important since these may be reproduced with considerable fidelity, while hue can only be suggested. It is, therefore, of preeminent importance that the problem of tone reproduction be thoroughly considered if one hopes to depict the true tonal relationships of an object in a lifelike manner.

Simplifying Assumptions.—In order to bring the theory of photographic tone reproduction within the limits of a single chapter, it will be necessary to make certain simplifying assumptions. First, while most subjects contain one or more colors, in the discussion which follows a monochromatic object will be assumed thus eliminating the complicating factors involved in the reproduction of the color sensation. This simplification becomes necessary, since, in general, the spectral sensitivity of the photographic plate is radically different from that of the human eye. Secondly, we shall further assume that all photographic deposits are non-selective and, therefore, have identical visual and photographic density values.

Tone Rendition of a Neutral Grey Object.—For convenience, the object to be reproduced will be regarded as consisting of a scale of neutral brightnesses lighted by reflected light. From the negative a lantern slide is made, which in turn is projected on a white screen. Let B_1, B_2, B_3, . . . represent the measured brightnesses of the 1st, 2nd, 3rd, . . . steps of the grey scale, and b_1, b_2, b_3, . . . represent the brightnesses of the corresponding steps on the screen. True tone reproduction would be achieved when each brightness of the screen image, b, is directly proportional to the brightness, B, of the corresponding part of the subject photographed.

Figure 142 is intended to represent schematically the set-up used in taking this picture. The step on the grey scale marked B_1 is imaged on the negative as T_1, B_2 as T_2, etc. The exposure (in meter-candle-seconds) reaching the film is directly proportional to the product of the brightness of the subject (in meter-candles) and the time of exposure (in seconds). This may be expressed mathematically as:

$$E = lB\tau_n \tag{1}$$

where E = exposure of the negative material in meter-candle-seconds,
B = brightness of the object in meter-candles,
τ_n = duration of the exposure in seconds,
l = a constant depending for its value upon the character of the image forming system. It may be shown from geometrical optics that $l = \pi/4(f/\text{number})$.[2]

From which it follows that the exposure E_1 for the first step of the grey scale would be represented by $E_1 = lB_1\tau_n$, the exposure for the second step by $E_2 = lB_2\tau_n$, and similarly for other steps.

Let us now further assume that the brightness range of the entire grey scale is such that it may be correctly recorded by the negative material, i.e., it can be recorded upon the straight line portion of the H and D curve of the negative material. Hence, the usual sensitometric formulas will apply. Let T_1, T_2, T_3, . . . represent the transparencies of the 1st, 2nd, 3rd, . . . steps of the negative upon development.

The equation on page 195 may be rewritten as:

$$T = \left(\frac{i_n}{E_n}\right)^{\gamma_n} \tag{2}$$

where T = transparency of the negative in percent
i_n = inertia of the negative material in meter-candle-seconds

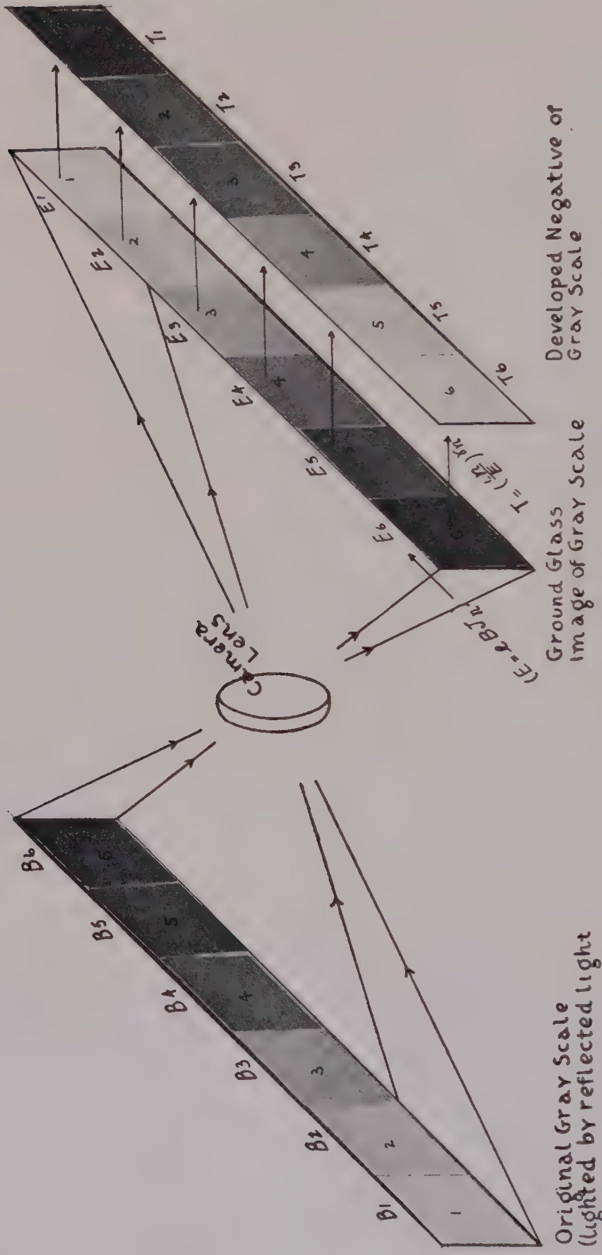
Original Gray Scale (lighted by reflected light)
B1
B2
B3
B4
B5
B6
1
2
3
4
5
6
Camera Lens
(E = kBJ^n)
Ground Glass Image of Gray Scale
E1
E2
E3
E4
E5
E6
T = (1/E)^γn
Developed Negative of Gray Scale
T1
T2
T3
T4
T5
T6

FIG. 142. Negative of Gray Scale

E_n = exposure given to the negative material in meter-candle-seconds

γ_n = degree of contrast to which the negative is developed, i.e., the slope of the H and D curve of the negative material.

From this we see that $T_1 = \left(\frac{i_n}{E_1}\right)^{\gamma_n}$, $T_2 = \left(\frac{i_n}{E_2}\right)^{\gamma_n}$, etc. for the other steps.

Next, a lantern slide positive is made by contact printing from this negative. This operation is represented schematically in Fig. 143.

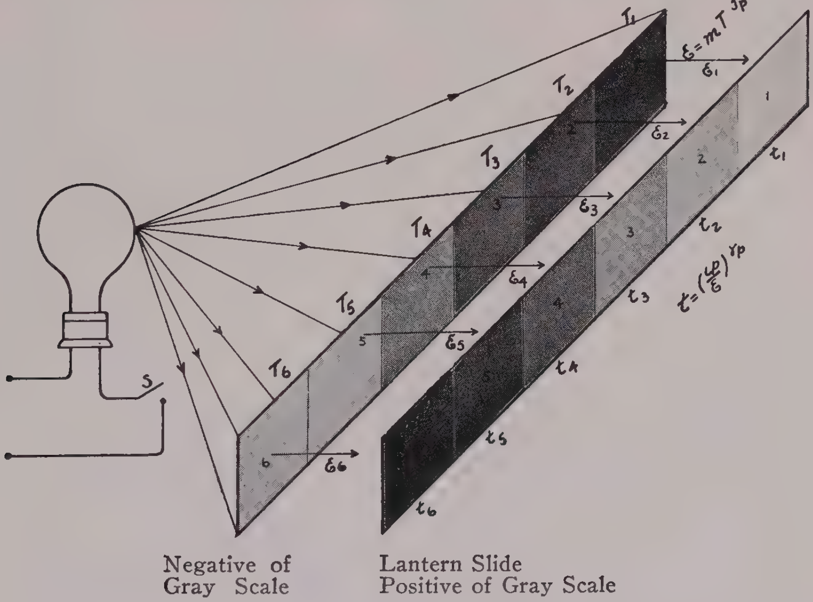

FIG. 143. Positive of Gray Scale

Here the exposure (in meter-candle-seconds) for any point on the lantern slide is directly proportional to the transparency of the corresponding point of the negative and to the time illuminated. This may be represented mathematically as

$$\mathcal{E} = mT\tau_p \tag{3}$$

where $\mathcal{E}$ = exposure received by the positive material, in meter-candle-seconds,

T = transparency of the negative in percent,

τ_p = time of illumination in seconds,
m = intensity of illumination on the negative in meter-candles. (This factor is solely a function of the design of the printer.)

The exposure $\mathcal{E}_1$ given the first step of the lantern slide will be represented by $\mathcal{E}_1 = T_1\tau_p$, the second step by $\mathcal{E}_2 = mT_2\tau_p$, etc. Let us now assume that the transparency scale of the negative is such that by selecting the proper printing time, it may be printed within the latitude of the positive material. If t_1, t_2, t_3, $\cdots$ represent the transparencies of the 1st, 2nd, 3rd, $\cdots$ steps of the lantern slide upon development, then

$$t = \left(\frac{i_p}{\mathcal{E}_p}\right)^{\gamma_p} \tag{4}$$

where t = transparency of the positive in percent,
i_p = inertia of the positive material in meter-candle-seconds,
$\mathcal{E}_p$ = exposure given to positive material in meter-candle-seconds,
γ_p = degree of contrast to which the positive is developed, i.e., the slope of the *H* and *D* curve of the positive material.

From this it follows that $t_1 = \left(\frac{i_p}{\mathcal{E}_1}\right)^{\gamma_p}$; $t_2 = \left(\frac{i_p}{\mathcal{E}_1}\right)^{\gamma_p}$, etc., for the other steps.

Now if this slide is placed in a suitable projector and the projector image of the grey scale examined as it appears on the screen (see Fig. 144), the brightness of any step of the grey scale will be directly proportional to the transparency of the corresponding step on the slide, or,

$$b = nt \tag{5}$$

where b = screen brightness of any particular section of the screen, in meter-candles,
t = transparency of the corresponding section of the lantern slide positive in per cent,
n = a factor representing the amount of light incident upon the slide in the projector (1/(f/number) ^{2}).

Therefore, the screen brightness of the first step of the grey scale will be represented by $b_1 = nt_1$, the second step by $b_2 = nt_2$, etc.

We are now in a position to analyze the conditions which must be satisfied if the screen brightness, b, at any point is to be directly proportional to the brightness, B, of the corresponding point in the subject.

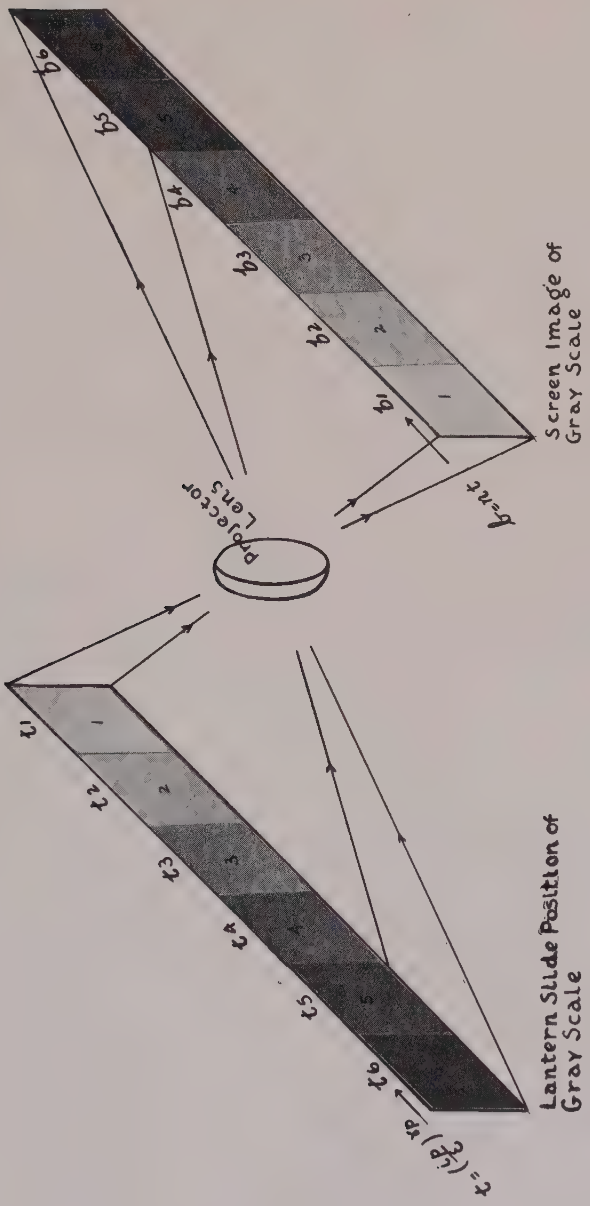
b6
b5
b4
b3
b2
b1
6
5
4
3
2
1
Screen Image of Gray Scale
Projector Lens
b=nt
t1
t2
t3
t4
t5
t6
Lantern Slide Position of Gray Scale
t=(d/d')dt

FIG. 144. Screen Image of Gray Scale

Starting with Eq. 5 and substituting the value of t as given by Eq. 4, we have

$$b = n\left(\frac{i_p}{\mathcal{E}}\right)^{\gamma_p}.$$

Substituting the value for $\mathcal{E}$ as given by Eq. 3, we have

$$b = n\left(\frac{i_p}{mT}\right)^{\gamma_p}.$$

Substituting the value for T as given by Eq. 2, we have

$$b = n\left(\frac{i_p}{m\left(\frac{i_n}{E}\right)^{\gamma_n}}\right)^{\gamma_p}.$$

And finally substituting the value for E as given by Eq. 1 we have

$$b = n\left(\frac{i_p}{m\left(\frac{i_n}{B}\right)^{\gamma_n}}\right)^{\gamma_p}. \tag{6}$$

If, for the sake of simplicity, we make the limiting assumption that both the negative and positive are developed to a gamma of unity, i.e.,

$$\gamma_n = \gamma_p = 1,$$

then Eq. 6 reduces to the form

$$b = \frac{nl}{m} \cdot \frac{i_p}{i_n} \cdot B, \tag{7}$$

which immediately indicates that b is directly proportional to B when both γ_n and γ_p are unity. It may be shown algebraically that the γ values of the negative and positive need not be unity individually, but only their product be unity. For example, if the negative is developed to a gamma of 0.5 and the positive to a gamma of 2.0, the reproduction of tone values is the same as would be secured were both the gamma of the negative and positive equal to unity. Thus it may be concluded that for the proportional reproduction of the brightness differences of the original, the product of the negative and positive gammas should be unity. In other words,

$$\gamma_n \cdot \gamma_p = 1.$$

However, it is important to remember that this entire argument has been built upon the following limiting assumptions:

1. That all the areas of the object photographed are both visually and photographically colorless.
2. That all the densities involved lie on the straight-line sections of the H & D curves.

Effect of Gamma Product on Tone Reproduction.—It will be of interest to consider how far the γ product of the negative and positive may deviate from unity without seriously affecting the reproduction or rendition of tone values. Assume, for example, a landscape in which the brightness range is approximately 32 to 1—that is, the brightness of the highest light is 32 times that of the deepest shadow. Denoting the highlight brightness by B_1 and the shadow brightness by B_2, the brightness range of the scene is:

$$\frac{B_1}{B_2} = 32.$$

Since most negative materials possess a latitude of 128 to 1 or more, it is possible with the proper camera exposure to record this range of brightnesses on the straight-line portion of the D-log E curve. Then the relation between the transparency of any given area of the developed negative and the brightness of the corresponding part of the subject may be represented as

$$T = \left(\frac{i_n}{E_n}\right)^{\gamma_n}.$$

By substitution it can be shown that the transparency range T_2/T_1 of the negative will be given by

$$\frac{T_2}{T_1} = \left(\frac{B_1}{B_2}\right)^{\gamma_n}. \tag{8}$$

With the aid of Eq. 4, it may be shown also that the transparency range of the positive is given by

$$\frac{t_1}{t_2} = \left(\frac{B_1}{B_2}\right)^{\gamma_n\gamma_p}. \tag{9}$$

An examination of Eq. 9 reveals that the gamma-product of the negative and positive is an exponential quantity. This means that even a slight deviation of the gamma product from unity will produce a relatively large change in the faithfulness of the tone rendition. When the gamma-product is larger than unity, the reproduction exhibits a greater contrast than the brightness range of the subject photographed; and when less than unity, the reproduction has less contrast than the original.

Enhancement of Contrast by Increasing Gamma Product.—For certain scientific applications it may be desirable to enhance the contrast of the original subject by developing both the negative and positive to a gamma-product greater than unity. In photomicrography, for example, details on the microscope slide which are invisible to the eye may frequently be effectively increased in this manner. This is possible since the eye has a minimum contrast sensitivity of approximately two per cent. Hence, brightness differences on the microscope slide which are less than two per cent will be indistinguishable to the eye. By extending the time of development it is quite possible to attain a gamma value of 2.0, while a gamma of 3.0 can be secured with some negative materials. Assuming a gamma of 3.0 for both the negative and positive, the gamma-product becomes 9.0. By such treatment, a brightness difference as small as 0.30 per cent can be increased to $0.30 \times 9 = 2.7$ per cent in the positive and therefore will become readily distinguishable with the eye.

The converse of this situation frequently arises. It may be necessary, for example, to photograph a subject where the brightness range is greater than that which can be recorded on the positive material available. In this case, it is necessary to develop both the negative and positive so that the product will be less than unity in order to secure faithful tone rendition.

A Graphical Solution of Tone Reproduction.—Thus far, only the correct reproduction on the screen of the actual physical brightnesses present in the object and of the actual contrast relations existing between various areas of the object has been considered. However, when the subjective impression produced by a given brightness is entirely dependent upon the state of adaptation of the observer's eye, it is obvious that such treatment as given above cannot represent a complete solution. The problem may be divided into two distinct phases: (1) the objective phase, which deals solely with the reproduction of the actual physical brightnesses and is capable of mathematical analysis; and (2) the subjective phase, which includes a consideration of those factors determining the nature of the subjective impressions produced by the action of a given physical stimulus under various conditions, and requiring the use of psycho-physical methods and data for its adequate treatment.

Heretofore, it has been assumed that all of the densities involved lie on the straight-line sections of the negative and positive H & D curves. In practice, this is not usually the case; it frequently becomes necessary to use the toe of the negative curve and both the toe and shoulder of the positive curve. An analysis of the rendition of tone values under these conditions becomes too complicated to express conveniently in mathematical language. However, a graphical solution, by Jones of the Eastman Kodak Research Laboratory, offers a most ingenious method of making this analysis. Fig. 145 presents this

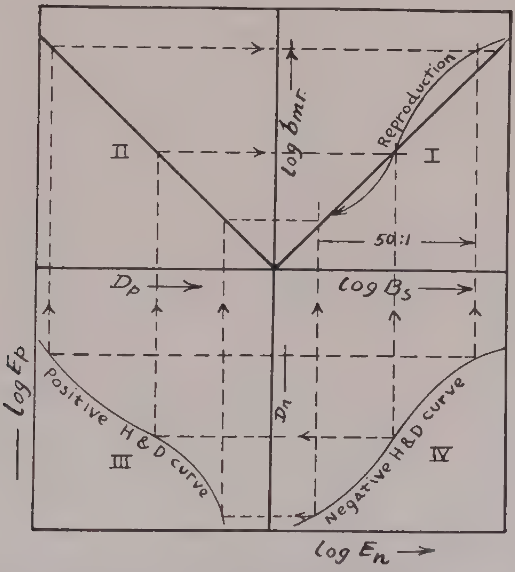

FIG. 145. Graphical Solution for Determining the Faithfulness of the Tone Reproduction for Typical Negative and Positive Materials

solution, the necessary curves being plotted in four quadrants designated for reference as I, II, III, and IV.

The fourth quadrant contains the characteristic H & D curve of the negative material;

The third quadrant, the characteristic H & D curve of the positive material, and

The second quadrant shows the variation in the response of the eye when viewing the original subject and when viewing the reproduction (the illuminated positive).

The first quadrant shows the extent to which accurate tone rendition has been achieved. The curve therein compares the visual sensation produced by the reproduction with that of the original. If the tone values are faithfully rendered, this curve will of necessity be a straight line at an angle of 45° to the axis.

In most of the cases encountered in practice, both the subject and the reproduction are viewed under adaptation levels which lie on the straight-line portion of the visual sensation curve (Fig. 146). Therefore, the relative subjective contrast function shown in the second quadrant of Fig. 145 appears as a straight line through the origin at 45°.

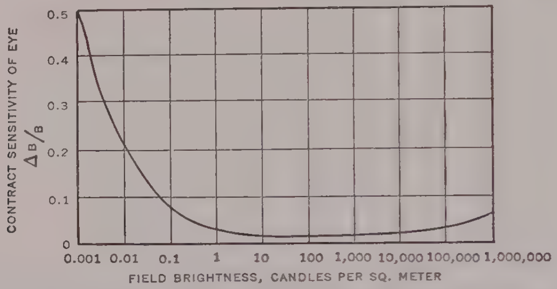

Fig. 146. Relative Contrast Sensitivity of a Normal Human Eye at Different Levels of Field Brightness Taken from Data of Konig and Brodhun and Adjusted for the Size of the Natural Pupil According to Data Furnished by Reeves.

From a study of the reproduction curve in the first quadrant of Fig. 145, it will be observed that the tone reproduction curve deviates quite markedly from linearity. The magnitude of the departure from an exact reproduction of the subject *brightness* is given by the length of a perpendicular line limited by the straight-line curve and the reproduction curve and drawn through the point considered; while the relation of the slopes of the curves at corresponding points determines the magnitude of the departure from exact reproduction of the *contrast* in the object at the point considered.

Analysis of Reproduction Curves.—The reproduction curve in Fig. 145 also indicates that the maximum contrast is secured from densities lying on the straight-line sections of the H & D curves of both the negative and positive materials. It will also be noted that the shapes of the toe and shoulder of the negative and positive curves works against one another in such a manner as to lower the reproduced contrast from these regions. Loss of subject detail in both the shadows and highlights is the result of this reduced contrast. Figs. 147, 148, and 149 are presented to show how the faithfulness of reproduction is affected through the utilization of negative and positive materials possessing various characteristics. From Fig. 147 it will be observed that the contrast in the shadows is enhanced, while that in the highlights is reduced. This occurs when the negative densities lie on the straight-line portion of the D-log E curve and are printed on a positive material having a long toe. From Fig. 148 it is seen that shadow contrast is lowered and highlight contrast enhanced when a negative in which many of the densities lie in the toe portion of the curve is printed on the straight-line portion of the positive material. Fig. 149 presents the ideal case where the straight-line portions of both the negative and positive materials are used exclusively. Here the reproduction curve in the first quadrant indicates that the tone rendition is correct.

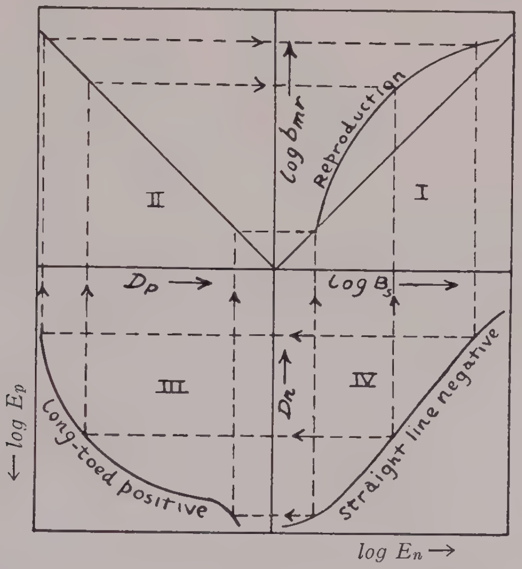

FIG. 147. Graphical Determination of the Faithfulness of the Tone Reproduction When Printing a Straight-line Negative on a Long-toed Positive

Tone Reproduction on Printing Papers.—The characteristic curve of printing papers is similar to that of negative materials except that the straight-line portion is shorter. The length of the straight-line portion, as projected on the log E axis, determines the range of brightnesses over which correct reproduction is obtained. Assuming

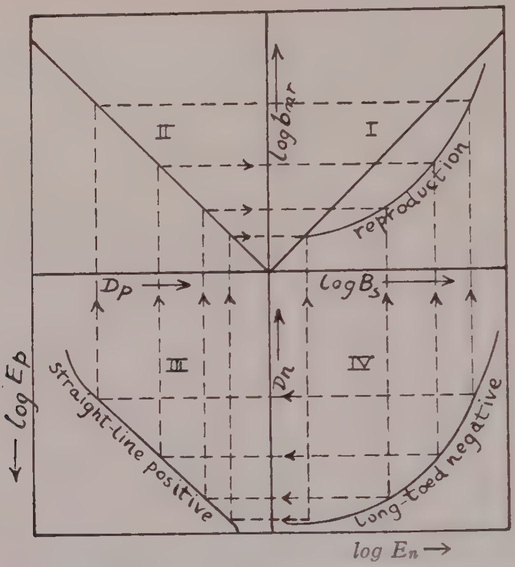

Fig. 148. Graphical Determination of the Faithfulness of the Tone Reproduction When Printing a Long-toed Negative on a Straight-lined Positive

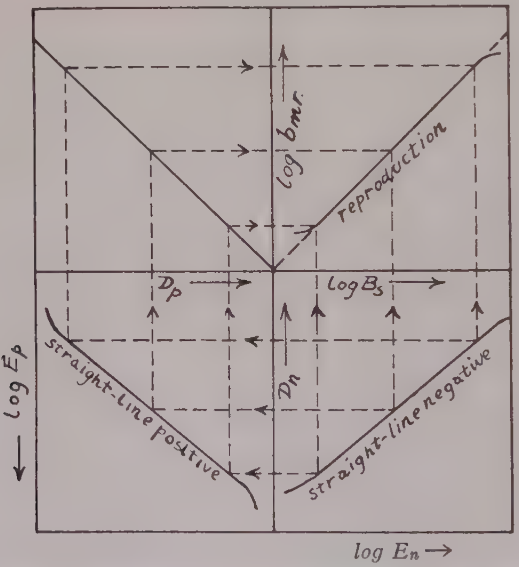

Fig. 149. Graphical Determination of the Faithfulness of the Tone Reproduction When Printing a Straight-line Negative on a Straight-line Positive

that the brightnesses of the subject are correctly represented by the opacities of the negative, proportional representation of the subject will be obtained if the straight-line portion of the curve of the printing paper is used and if the product of the negative and positive gammas is equal to unity.

A good negative material is capable of recording proportionally a brightness range of 1:128 or more. Since printing papers depend upon reflected rather than transmitted light, they are limited to the difference between the amount of light reflected from the white paper and that reflected from the deepest black which the paper will produce. The maximum black obtainable with any paper varies with the emulsion and the surface of the paper. With a matt paper, the difference in the amount of light reflected from the unexposed paper and the maximum black may be in the ratio of 1:15; with glossy papers, the ratio is greater, usually from 1:50 to as high as 1:100. Hence, it is possible to reproduce the full scale of brightnesses in the subject photographed if the entire scale of the paper is used. The limits of *correct* rendering, however, are fixed by the range of brightnesses included in the straight-line portion of the characteristic curve of the paper. Unfortunately, however, the total range of brightnesses in the average subject cannot usually be included within the straight-line portion of the paper curve.

Since accurate reproduction is possible only for a limited brightness range, it is necessary to sacrifice the reproduction of those parts of the tone scale that are of minor importance in order that the portion holding the greater subject interest may be properly rendered.

In practice, the tone reproduction obtained on a printing paper is controlled (1) through the choice of a paper the exposure scale of which is suitable for the opacity range of those portions of the negative which represent the most interesting parts of the subject and (2) by adjusting the printing exposure to obtain the tonal differences which are regarded as suitable for the subject as a whole.

Three examples may serve to show how these principles are applied to the problem of tone reproduction in printing.[1]

I. Suppose one wishes to print a rather contrasty negative of an open landscape having a dense sky without clouds in which the interest lies chiefly in the foreground. If a paper is chosen having a scale which will record the deepest shadows in both the foreground and sky, the foreground detail will fall on the overexposure portion of the paper curve and hence will be flat and lacking in contrast. For such a case it would be better to regard the scale of the negative as the difference between the lowest and the highest density in the foreground alone. Then, if a paper is selected having sufficient latitude to record this range on its straight-line section, correct rendering will be obtained for the most important part of the subject.

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[1] Mees, Jones and Nutting, *Phot. Jl.*, **54** (1914), 342; Mees, **64** (1924), 311.

II. In a similar landscape where the chief interest is in the cloud formations, the conditions would be exactly the reverse of Case I. Here it would be the highlight gradations that we would attempt to record faithfully.

III. Let us now consider a scene in which the objects of major interest consist of middle scale values surrounded by strong highlights and shadows. Under these conditions the negative gradation is very much greater than can be recorded on paper. Consequently we shall endeavor to render properly the half-tone region and let the shadows and highlights take care of themselves. This can be achieved by selecting the proper paper and giving the correct exposure to record the object of greatest interest on the straight-line portion of the *H* and *D* curve. Obviously the rendition of the highlights and shadows will be distorted, the amount of distortion depending upon the shape of the toe and shoulder of the characteristic curve of positive material. Naturally, the greater the latitude of the paper, the more perfectly the extremes will be reproduced.

CHAPTER IX

THE REPRODUCTION OF COLOR IN MONOCHROME

Introduction.—The vast majority of subjects photographed contain objects of different colors which can be represented only as differences in tone. The extent to which this is possible and the conditions under which the photographic process will produce the desired result are matters of considerable importance. Differences in color are due to differences in hue, in saturation, or in brilliance.[1] Differences in hue and saturation cannot be reproduced in monochrome, hence, with the usual processes of photography, it is necessary to reproduce differences in color which may be due to variations in hue, saturation or brilliance by means of the latter characteristic alone.

In this chapter we are concerned (1) with the relation between the wave length of radiation and the resulting sensation, i.e., the visual function, (2) the relation between the spectral sensitivity characteristics of photographic negative materials and the rendering of color, and (3) the means employed for modifying the effective distribution of sensitivity so as to produce the most satisfactory rendering of color differences in monochrome (color filters).

The Brilliance Characteristic of Color.—The relation between the wave length of radiation and the brilliance of the resulting sensation may be represented, assuming equal amounts of radiation in all parts of the spectrum, by a curve of the type shown in Fig. 150. In other words, if a series of colored objects reflecting the same amounts of radiant energy are compared by light of the average intensity of diffuse daylight, the yellow object will appear more brilliant than any of the others. Green and orange will be less brilliant but more so than red or blue, while violet and deep red will be the least brilliant of all.

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[1] Definitions: *Hue.* The attributes of color in respect of which it differs from grey; the attribute in respect of which colors may be classified as red, green, etc. *Saturation.* The distinctness or vividness of hue. *Brilliance.* The attribute of color without which color cannot exist; the attribute in respect of which all the colors may be classified as equivalent to one or another of a series of greys of which black and white are the dominant members. From Glazebrook, *Dictionary of Applied Physics.*

Reproduction of Color with Photographic Materials.—The result produced when photographic materials are exposed in the same manner, i.e., to a series of colors reflecting the same amounts of radiant energy, varies with the distribution of spectral sensitivity in the material. The greater the sensitivity of the material in any part of the spectrum, the greater the density of the negative and the lighter the tone of grey in which the corresponding color sensation is reproduced in the positive.

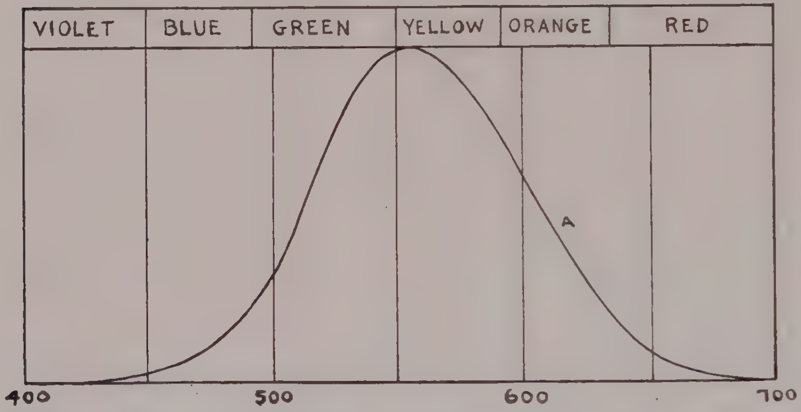

FIG. 150. Color Brilliance Curve Showing Relation Between Wave Length of Radiation and Intensity of Visual Responses

Photographic materials differ considerably as respects the distribution of sensitivity in different parts of the spectrum and this characteristic will be discussed at length in Chapter X. Ordinary, or blue sensitive, materials are for all practical purposes insensitive to radiation of a wave length longer than 550 millimicrons; therefore, those colors which appear brightest to the eye are rendered almost black. The range of orthochromatic or isochromatic materials extends to a wave length of approximately 600 millimicrons and thus are sensitive to green as well as to violet and blue. They are practically insensitive to pure orange and red, both of which are relatively brilliant to the eye. Panchromatic materials are sensitive to the entire visible spectrum and it is only through the use of negative materials of this type that objects in color can be rendered in the correct relative tone values as seen by the eye. The response of a panchromatic material to the different parts of the spectrum, however, is not the same as that of the eye and depends not only on the spectral sensitivity characteristics of the sensitive material but on the distribution of energy in the spectrum of the illumination to which the film or plate is exposed. Thus the relative tone values in which colors are reproduced by a photographic material depend not only on the spectral sensitivity of the film or plate but on the light source employed in making the picture.

Effect of the Light Source on the Reproduction of Color.—Curves representing the relation between energy and wave length for several of the more important sources of illumination employed in photography are shown in Fig. 151 to 153.

Skylight. Skylight represents sunlight which has been scattered by dust, water vapor and air. It is distinctly blue as compared with sunlight.

Carbon Arc. The spectral distribution of an ordinary carbon arc is practically equivalent to a color temperature of 4000° K. (Fig. 151).

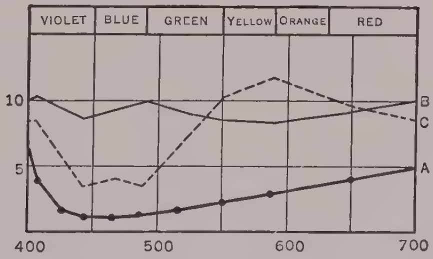

FIG. 151. Spectral Energy Curves of (*A*) Carbon Arc, (*B*) White Flame Carbon Arc, (*C*) Panchromatic Carbon Arc

The white flame and panchromatic (orange) arcs are produced by the addition of suitable metallic compounds to the carbon.[2]

Tungsten Sources. The spectrum of incandescent tungsten radiation varies with the temperature of the filament which depends upon the type of lamp and the voltage at which it is operated. The maximum filament temperature in degrees Kelvin, corresponding to the color temperature, for some of the more widely used types of incandescent lamps is as follows:

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[2] Joy & Downes: *Trans. Soc. Mot. Pict. Eng.* 12 (1928), 502.

Lamps	Watts	Volts	Bulb	Maximum True Temperature (Degrees K.)
General Service	500	115	PS-40	2935
General Service	1000	115	PS-52	3000
General Service	1500	115	PS-52	3020
(Movieflood)	2000 C.P.	115	PS-52	3380
Projection (Monoplane)	500	115	T-20	3265
Photoflood No. 1	250	115	A-21	3490
Photoflood No. 2	500	115	A-25	3430
Photoflood No. 4	1000	115	PS-35	3410
Photoflash				3500 (Average color temperature)

The curves of Figure 152 show the spectral energy curves of incandescent tungsten sources for color temperatures ranging from 2800° to 3500° K. These are drawn in the conventional manner through a common point representing 100 per cent relative energy at 5600° A.[3]

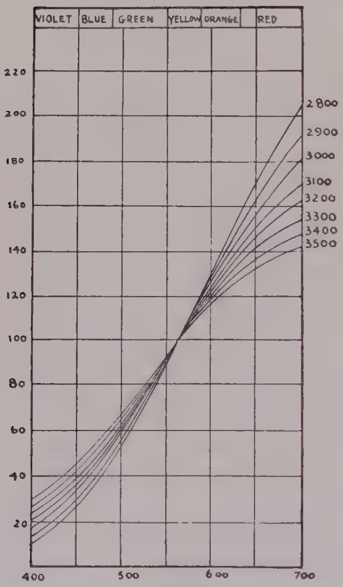

FIG. 152. Spectral Energy Curve for Tungsten Sources

Mercury Vapor Lamps. The light emitted by mercury vapor lamps is confined to a few bright lines in the violet, blue and green. (See Fig. 153.) It is not, therefore, a suitable light source for photographing colored objects. Mercury vapor lamps are sometimes employed in conjunction with incandescent lamps to obtain better color rendering. The exact balance between the two depends upon the color sensitivity of the plate or film employed and the type of incandescent lamp used.

Flash Powders and Photoflash Bulbs. The spectral character of the light produced by flashlight powders varies with the composition of the mixture. More recently mixtures containing substances producing a greater abundance of long-wave radiation have been introduced. These are frequently referred to as "panchromatic" mixtures.

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[3] Data from Farnham and Worstell: Color Quality of Incandescent Lamps, *J. Soc. Mot. Pict. Eng.* **27** (1936), 260.

The spectral energy distribution of flashlamps varies slightly in different makes and types. The typical aluminum foil lamp has a color temperature of approximately 3500° K. (Fig. 152).[4]

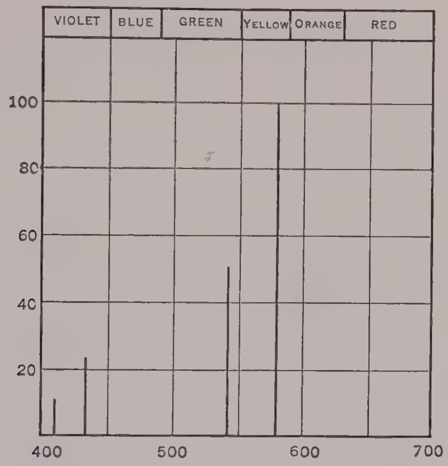

FIG. 153. Spectral Energy Curve Mercury Vapor Illumination

Color Filters.—The spectral response of a photographic material, and, hence, relative brightness in which colors are rendered with any given photographic material and light source may be altered by the introduction of a screen possessing selective absorption. Such screens are known as filters. Thus, if a screen which transmits yellow, green, and red freely but absorbs some of the violet and blue is placed at any point between the light source and the sensitive material the photographic effect of blue and violet is reduced because some of the light which would affect the sensitive material is absorbed by the filter. Consequently, violet and blue are rendered darker and green and red lighter, relatively, since the latter are transmitted by the filter with little or no absorption. Filters thus provide a means of controlling the relative brightnesses in which the colors of the subject are rendered.

Filter Factors.—Since the employment of a filter results in the

[4] Farnham & Worstell: *J. Soc. Mot. Pict. Eng.* 27 (1936), 260.

POTAPENKO—Theory and Technique of Light Filters. (Appended to this paper is a very complete bibliography of 115 papers on light filters in various photographic and other technical journals.) Brit. J. Phot., **68** (1921), 507, 522, 534.

absorption of light in a spectral region to which the photographic material is sensitive, it is obvious that the effective illumination is reduced, necessitating an increased exposure. The number of times the exposure must be increased when using a filter is known as the filter factor.

The filter factor depends on (1) the absorption spectrum of the filter, (2) the spectral sensitivity of the photographic material with which it is used and (3) the distribution of spectral energy in the illumination incident on the subject photographed.

Thus a filter which absorbed totally all radiation between 300 mμ and 400 mμ (violet and blue) would reduce the sensitiveness of an ordinary (blue-sensitive) material almost to the vanishing point. In the case of an orthochromatic material the effect on sensitiveness would be less because a larger proportion of the total sensitivity lies in spectral regions which are not absorbed by the filter. The effect on a panchromatic material will be even less and for the same reason. Hence, the filter factor for the same filter will be much greater for ordinary than for orthochromatic material and still less for panchromatic material. With a filter transmitting between 300 mμ and 400 mμ and absorbing the remainder of the spectrum, the effect will be reversed.

The filter factor varies also with the distribution of energy in the illumination incident on the subject. The greater the proportion of the total energy which lies in the spectral region transmitted by the filter, the lower the filter factor.

For example, tungsten radiation contains a larger proportion of yellow, orange, and red light and less violet and blue than daylight. Therefore, the factors for yellow, orange, and red filters are lower for tungsten than for daylight. The reverse is true, however, of a blue filter.

The factor of a filter, therefore, cannot be expressed except in terms of a particular sensitive material and source of illumination.

Determination of Filter Factors.—For general purposes, the published factors are satisfactory; however, in making three-color negatives and certain other cases it is at times necessary to determine

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Davis—A New Method of Measuring the Factors of Light Filters. Phot. J., **61** (1921), 169.

Jones and McFarlane—The Precise Measurement of Filter Factors and Photographic Reflecting Powers. J. Soc. Mot. Pict. Eng., **19** (1932), 361–390.

the factors applying under conditions not contemplated in the published values.

There are two methods by which the factor of a filter may be determined:

1. Two sensitometric strips are exposed one with and one without the filter whose factor is to be determined. Usually it is necessary to increase the exposures on the strip made with the filter in order to obtain sufficient exposure for purposes of calculation. When this is necessary, the difference in exposure must be taken into consideration when calculating the filter factor. Having selected a suitable density on the strip exposed without the filter, the equivalent density located by visual inspection of the strip exposed with the filter and the ratio of the two exposures for the two steps determined.

Greater precision is obtainable by measuring the densities on the two sensitometer strips, plotting D-log E curves and determining the exposures corresponding to a given density. The ratio of the two exposures is the filter factor.

2. Practical filter factors may be conveniently determined by photographing a black and white photograph with and without the filter. The photograph should be a neutral black; blue-black or brownish black prints are not advisable. A series of exposures is made, preferably by varying the lens aperture so as to avoid variations in shutter speeds, first without and then with the filter. This series of exposures may all be made on a single film or plate by means of a "Ratiometer" which consists of a deep box lined with velvet, on top of which slides a black and white print. The first exposure is made with the print at the left. It is then shifted towards the right a distance equal to its width and the second exposure made. The same procedure is followed for the remaining exposures.

After development, the series of negatives made with the filter is compared with the other and the images selected which match in the highlight region. The filter factor is calculated from the ratio of the exposures for the two negatives.

Orthochromatic Filters. Orthochromatic Reproduction.—Filters may be used either to correctely render in monochrome the differences in the brilliance of the colors of the subject (orthochromatic reproduction) or to reproduce a particular color, or colors, darker or lighter in order to obtain greater contrast than would be obtained with orthochromatic rendering. Filters designed to produce orthochromatic reproduction are appropriately termed orthochromatic filters, while filters designed to increase contrast are termed contrast filters.[5]

For true orthochromatic rendering it is necessary that the spectral response of the photographic material be made to correspond with that of the eye. In other words, the effective distribution of photographic sensitivity should correspond with the response of the eye as represented by the color brilliance curve. With the sources of illumination in general use in photography, it is necessary to employ filters if this result is to be obtained. The spectral absorption characteristics of the filter necessary for orthochromatic reproduction with any particular film or plate is found by subtracting the ordinates of the color brilliance curve from those of the curve representing the distribution of spectral sensitivity.

To obtain orthochromatic reproduction with the panchromatic materials available, it is necessary to reduce the effect of violet and blue, and in certain cases, red. Materials whose sensitivity is excessive only in the violet and blue require yellow (violet and blue absorption) filters. With panchromatic materials designated as supersensitive or hypersensitive, the use of a light source rich in long wave radiation, for example, incandescent tungsten, results in a secondary maximum of sensitivity in the orange-red and for orthochromatic reproduction, the filter must absorb some orange and red as well as blue and violet. Such filters appear a pale green by transmitted light.

Contrast Filters, Using Filters for Color Selection.—In practice, orthochromatic reproduction is not always the end in view. Objects are distinguished from their surroundings by *contrast* which may be the result of a difference in brightness or a difference in color. Frequently, parts of the subject may differ but little in brightness and yet the contrast may be considerable because of a difference in color. The contrast between a bright red apple amidst a cluster of green leaves, for example, is very striking to the eye. Actually, however, the brightness difference is small and when photographed on a panchromatic material with an orthochromatic filter the contrast is insufficient and the two are not properly differentiated in the negative.

Since color contrast can be reproduced in monochrome only as differences in brightness, in the case of a subject of this nature contrast must be produced by darkening or lightening the tone in which one of the colors is reproduced in relation to the other. This may be accomplished by using a filter which absorbs more of one of the colors than the other. Consider the case of a tree with red apples. A green filter will render foliage lighter than the apples while a red filter partially absorbing green will render the apples relatively lighter than the foliage. Consequently, to render a color *lighter* than it would appear with orthochromatic reproduction a filter which selectively *transmits light* of the same color must be used, while to render a color *darker,* it must be photographed with a filter which *absorbs* light of the same color.

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[5] Orthochromatic, from the Greek roots, *ortho* correct and *chroma* color, is here used in its true significance; orthochromatic films and plates do not result in orthochromatic reproduction but only in an improved rendering of color as compared with blue-sensitive materials.

Contrast filters find many applications in commercial and technical photography. In photographing a white building outlined against the sky, for example, the use of a deep yellow or orange filter darkens the sky and increases the contrast between it and the building. Contrast filters are also useful in cutting through atmospheric haze when photographing distant subjects or subjects in a dull, hazy light. Furniture, particularly if dark, almost invariably requires a contrast filter to obtain the contrast required to reveal the characteristic grain of the wood and tapestries, colored labels and packages also are among the many subjects which necessitate the frequent use of contrast filters.

Choice of Filter.—The proper filter to use under any given conditions depends upon the subject and involves a decision first as to what color, or colors, are to be rendered lighter (or darker) and second, the degree of contrast to be produced. As a general rule, the warm colors such as yellow, yellow-green, orange and red should be rendered as lighter than the cool colors such as violet, blue and blue-green. The extent to which a color should be lightened or darkened depends so much upon the subject and the results desired that no definite rule can be given; judgment based upon experience is the only safe guide.

Viewing Filters.—It is extremely useful to be able to determine before making an exposure the rendering of color values which may be expected with a particular sensitive material and filter. Viewing filters designed for this purpose are obtainable from a number of sources.[6] A fair approximation of the result which may be expected with a blue sensitive plate or film may be obtained by viewing the subject through a blue-violet filter, such as that used for making three color negatives. No filter is able to completely remove the effect of color without affecting the relative tonal values, but a satisfactory approximation of the results obtained with a panchromatic material and a fully correcting orthochromatic filter can be gained by viewing the subject through a pure yellow filter such as the Wratten No. 90 or the Ilford P. V. Pan filter. The effect of a contrast filter may be determined simply by examining the subject through the filter. In using filters in this way, it is important not to be misled by color; one must learn rather to look for the effect of the filter on the *contrast* of different parts of the image.

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[6] Photographic vision filter; Ilford Limited, London. Monochromatic Viewing Filter and Filter Test Chart; Eastman Kodak Co., Rochester. Schiebe Viewing Screen; Schiebe, Los Angeles.

Filters in Landscape Photography.—Among the chief uses of filters in landscape work are for the purpose of:

1. *Securing clouds in the sky and controlling the intensity of the sky.* With modern orthochromatic and panchromatic materials, only a comparatively light yellow filter is required to darken the sky sufficiently to bring out clouds with the proper contrast. The use of yellow contrast, or minus blue filters, darken the sky considerably and increase the contrast between the clouds and the sky. Still greater contrast is obtained by using a red filter and panchromatic film or with infra-red material. Another application of filters is for the purpose of lowering the brightness of the sky so as to prevent excessive contrast when near dark objects are outlined against the sky.

In architectural photography, minus blue or orange-red filters are sometimes required when photographing white or light colored structures outlined against the sky to darken the sky and provide sufficient contrast between the buildings and the sky.

2. *To improve rendering of colors of foliage, flowers, etc.* Photographers have become so accustomed to the incorrect rendering of blue-sensitive material that photographs which correctly portray the luminosities of the subject are often regarded as overcorrected. Grass and foliage is in general rendered too dark without filters and by not preserving the proper differences in color luminosities, the effect of aerial perspective is destroyed. With modern orthochromatic and panchromatic materials, only light filters are necessary. Care

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Mees—Luminosity Filters. Brit. J. Phot., **53** (1906), 430.

Renwick—Color Values in Monochrome and a New Viewing Filter to Assist in Obtaining Them. Phot. J., **59** (1919), 158.

should be taken not to overcorrect through the use of filters which are too strong.

3. *To penetrate haze and secure sharp definition on distant objects.* The intervening haze which obscures distant objects is due largely to the scattering effect of particles of water vapor in the atmosphere. The scattering effect of these particles of water vapor, at a maximum in the ultra-violet, decreases progressively with longer wave lengths. Hence, the use of filters which absorb the ultra-violet and violet will result in an improvement in the definition on distant objects. With strong yellow, orange, or red filters, absorbing more and more of the light rays scattered by the particles of dust and water vapor, its effect is lessened and the definition of distant objects improved.

In landscape work, the total elimination of haze is not generally desirable as the recession of planes due to the effect of the atmosphere is destroyed and distant objects are made to appear too close to the camera. In mountain work and in telephotography, however, sharp-cutting yellow or orange-red filters are decidedly useful and in many cases absolutely necessary if satisfactory results are to be obtained. The lightest filter generally suitable for work of this kind is the minus blue; that is, a filter which absorbs ultra-violet, violet and blue. Greater penetration of haze is obtainable with a strong yellow filter, such as the Wratten G, or an orange-red filter such as the Wratten A. For maximum penetration of haze, infra-red materials should be used with appropriate filters (p. 247).

Filters in Portrait Photography.—Color filters are not generally used in portrait photography, partly perhaps on account of tradition, partly on account of the increased exposure required, and partly because of the general practice of retouching.

Flesh values are recorded satisfactorily with modern panchromatic materials without the need of a filter. Panchromatic materials having a high orange-red sensitivity tend towards the overcorrection of flesh values when exposed by clear tungsten illumination. To offset this tendency, blue-glass (photo blue) bulbs are frequently employed either alone or in combination with clear tungsten illumination.

Filters in Commercial Photography.—Filters are used in so many different ways in commercial photography than no general treatment of the subject is of much value. In general, modern practice is to use filters on virtually every colored object except in cases where a satisfactory rendering is obtainable without a filter. Both orthochromatic and contrast filters are used depending upon the end in view.

Generally, strict orthochromatic reproduction is regarded as important only if the print is to be colored or if the reproduction of the color differences of the original is of paramount importance. In the larger number of cases, the aim is to produce in the photograph the degree of contrast between the different colors which is regarded as suitable for that particular subject. However, a few examples may be useful. Panchromatic materials and contrast filters are virtually necessary in photographing furniture. It is almost impossible, for example, to secure a satisfactory rendering of red mahogany on an ordinary, blue sensitive film or plate, or even on an orthochromatic material except with a lengthy exposure but with a panchromatic material and a red filter the grain of the wood is brought out so clearly as to be almost incredible. With yellow woods, such as oak, satinwood and walnut like results will be obtained with a strong yellow filter. Tapestries and carpets require either orthochromatic or contrast filters as do colored posters, labels, colored maps, sepia-toned photographs, purple violet or blue typewriting (green filter), blue print (red filter), stained prints (filter the color or the stain, weathered brick buildings (strong yellow, orange, or even red filters).

Optical Properties of Light Filters.—Light filters are produced in one of three ways:

1. By dyeing thin sheets of gelatin with suitable dyes to produce a gelatin film filter which may be used alone or cemented between first quality glass for greater protection.

2. By infusing the molten glass during manufacture with suitable coloring materials.

3. By colored liquids contained in cells of glass or other suitable materials.

The first method is by far the most important. A large number of suitable dyes is available and filters having almost any desired absorption characteristics may be prepared. The gelatin film is easily damaged but this is avoided by cementing it between two pieces of glass. Filters produced in this manner are quite satisfactory if the cementing has been done properly and the glass is flat; the only drawback is that heat, moisture or excessive strain may cause the cement to soften, or give way, thus producing inequalities in the filter which affect its performance.

The number of colored substances which may be added to molten glass in the process of manufacture is rather limited and the production of colored glass filters has been hampered: (1) by the difficulty in finding substances having the required spectral absorption and (2) by the difficulty experienced in producing a uniform product. Colored glass filters are rather more durable than those formed by cementing gelatin film between glass, but their absorption characteristics are not as well adapted to the requirements of modern color-sensitive materials.

Liquid filters are now seldom employed, except for special purposes, owing to their bulk, inconvenience and rapid deterioration.

Gelatin film filters, owing to their thinness, are practically without effect on the definition of the lens.

For ordinary purposes, filters prepared by cementing the gelatin film between carefully selected pieces of optical glass are satisfactory if the cementing is done carefully to avoid strains in the glass. To ensure satisfaction, however, only filters of the highest repute should be chosen. Cheap filters are poor economy; as filters, they are frequently ill adapted to the requirements of modern sensitive materials while the glasses used are neither plane nor parallel and the cementing faulty. With long focus and telephoto lenses and the large aperture lenses used on miniature cameras, it is especially important that only filters of the highest quality be used.

For three-color process work filters cemented in optical flats and tested to work together must be used if three equal-sized images are to be obtained.

The filter may be placed in one of several positions:

1. *Over the light source.* This is the usual position in photomicrography and other branches of photography in which small light sources are used as in this position the filter cannot possibly affect the definition of the lens image.

2. *In front of the sensitive material.* This involves the use of larger filters than when used over the lens but is the most convenient method in repeating backs for making three-color negatives and in tri-color cameras.

3. *Between the lens combinations.* This position is possible only with gelatin film filters.

4. *Before the lens.* In general, this is the best position for the filter. In this position, it is more accessible and has the further advantage that any imperfections in the filter have less effect than if placed behind the lens. Moreover, the focal length of the lens, for all practical purposes, remains unchanged. This is obviously an important consideration when using a filter on cameras focused by scale.

5. *Behind the lens.* This position is less suitable than in front of

the lens for the reasons mentioned above, and also because placing the filter behind the lens displaces the image by a distance which is approximately one-third of the thickness of the filter.

Care of Filters.—Because gelatin filters are easily marked, they should be handled as little as possible. The best way to use them is, when possible, to place the filter between the combination of the lens where it will be protected. Film filters may also be used in caps which slip on over the front of the lens, but exposure to moisture will in time cause them to cloud.

Cemented filters should receive the same careful attention as a lens. They should be kept clean by polishing them from time to time with a piece of lens tissue or silk. If necessary, a clean cloth moistened with alcohol may be used to clean the glass surface of a filter. In doing so, care should be taken not to allow the alcohol to reach the edges as the cement may be softened, allowing air to enter. Cemented filters should be protected from heat because by its softening the balsam, a strain may be set up which may affect the definition of the lens with which the filter is used.

Most filters are quite stable to light; yet excessive exposure to strong light should be avoided.

CHAPTER X

NEGATIVE MATERIALS

Forms of Negative Materials.—Sensitive materials for negative making are supplied in four forms: glass plates, cut film, roll film and film pack.

Glass Plates and Cut Film.—Glass has formed the support for negative materials since the early days of photography and not until 1892 when the nitrocellulose film was introduced was its supremacy questioned. Today, glass plates have largely been superseded by film, but in certain specialized fields of photography in which the dimensional accuracy of the image is an important factor, as in spectrography, astronomy and in photo-engraving, glass plates are still employed.

Glass plates are packed in pairs with the emulsion sides facing while cut films are usually packed with the emulsion side facing the same way and separated with sheets of black paper specially selected and treated to be free of injurious substances. Both plates and cut films are ordinarily packed in boxes containing one dozen. The plates, or films, are wrapped first in black paper and then in metal foil, or waterproof paper, to provide added protection from moisture. In America, both plates and films are packed in three-part boxes for added protection from light, while British and foreign materials are usually packed in a box with a single cover and the box itself enclosed in a sealed paper wrapper.

Both plates and cut films are best placed in holders in total darkness, as the danger of fog from exposure to the safelight is much greater when the material is dry than after development has begun. The emulsion side of cut film is usually indicated by notches which are placed so as to be in the upper right hand corner when the emulsion side is facing the observer. In most American-made films, the number and shape of these notches are used to indicate the type of film. The emulsion side of glass plates may be identified by the reflection of the safelight in the glass side, or, when loading in total darkness, by remembering that the odd-numbered plates lie face down and the even numbers face up, or by slightly moistening the tips of the thumb and forefinger and applying to the opposite sides of the plate at one corner.

The moistened finger will adhere to the emulsion-coated side. Films are usually quite free of dust, but with glass plates the emulsion side should be brushed lightly with a soft camel's hair brush to remove adhering dust. In many cases, it is sufficient to strike the edge of the plate sharply against the edge of the work table.

If it is necessary to remove exposed plates, or cut film, from the holders before development they may be kept for some time in the original boxes wrapped exactly as received from the manufacturer, but the black separating papers used in packing films should not be used a second time. Plates, or film, should not be wrapped in any paper except that used for this purpose by the manufacturer as others papers may contain substances which lead to fog or fading of the image.

Roll Film.—The manner in which roll film is made daylight loading is shown in Fig. 154. The strip of film is attached at one end with an adhesive sticker to a long strip of opaque paper. Then, when the film is wrapped around the spool, the end of the paper strip protruding beyond the film protects the film from light so that it may be placed in the camera in daylight. The strip of paper extending beyond the other end of the film strip operates in the same way to permit removal of the film from the camera in daylight.

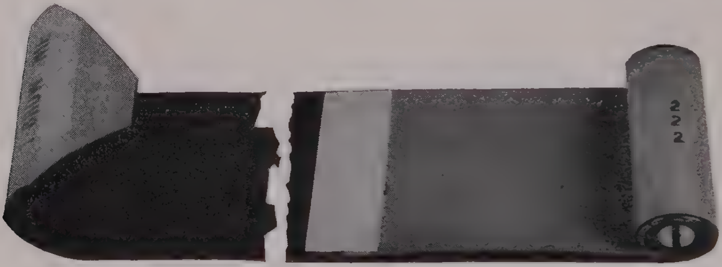

FIG. 154

Roll film employs a thinner base than cut film as greater flexibility is required. Both are invariably coated on the back with a layer of gelatin to prevent curling. A dye which is decolorized by the de-

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HILL AND WEBER—Stability of Motion-Picture Films as Determined by Accelerated Aging. J. Soc. Mot. Pict. Eng., **27** (1936), 677.

FRANKEL—Process for the Production of Matt Photographic Emulsions. G.P. 562,618. Phot. Ind. (1932), 1286.

SHEPPARD—Matte Surface (Eastman Kodak Co.). U.S.P. 2,043,906 of 23.3.35.

veloper, or the fixing bath, is frequently added to this gelatin layer to form a backing to prevent halation. (See p. 248.)

A number of makes of roll film, particularly those intended for miniature cameras, have a protective coating of gelatin over the emulsion to prevent scratching of the emulsion from contact with grit or other sharp objects in the camera, or before processing.[1]

Film Pack.—The film-pack, like roll film, may be placed in, or removed from, the camera, or adapter, in daylight. It enables 12 exposures to be made without reloading and, unlike roll film, any number of exposed films may be removed in a darkroom for development without affecting the remainder. On the other hand, there are several disadvantages of existing film packs compared with roll film; (1) there is greater danger of scratching and accidental light fog, and (2) in the larger sizes particularly, the film is not as flat in the exposure plane; a shortcoming which, with large aperture lenses, may affect the definition of the image.

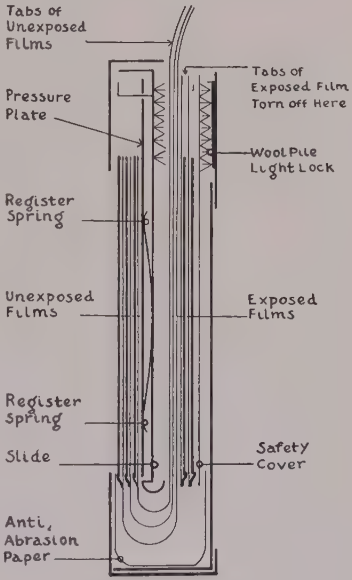

Fig. 155. Cross Section of Film Pack (Eastman Kodak Co.)

The principle of the film pack is shown in Fig. 155. Twelve cut films each attached to an opaque black paper tab are placed in a metal or cardboard container. The ends of the paper tabs project from the top of the pack and by pulling out the tab the film is transferred from its position at the front of the pack to the rear section. In front of the pack is an opaque black paper "safety cover" which protects the films from light until the pack is placed in the camera, or in the light-tight adapter. This safety cover is transferred to the rear of the pack by pulling out the safety tab before the first exposure is made. When the last exposure is made, the pack is rendered light-tight by the center partition which is now in front in the position occupied in the beginning by the safety cover.

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[1] In order to facilitate retouching on the back of film negatives, a number of manufacturers have introduced films in which the back is coated with gelatin containing a fine transparent abrasive material. This produces a matte back which readily accepts retouching without special preparation. A matte-back also tends to minimize the effect of scratches on the back of the film.

Storage of Sensitive Materials.—Exposed plates, or film, which must be kept for some time prior to development in a humid, tropical atmosphere should, if possible, be first desiccated by placing in an airtight compartment containing calcium chloride, which extracts moisture from the air. After several hours in such a desiccator, the film or plates should be transferred to airtight metal containers and sealed. If this procedure is impractical, the package may be packed tightly in a box filled with crumpled photographic paper which should be removed and dried daily in an oven, or before a fire. Thus protected from moisture, the film will keep in good condition for several weeks although it is best to arrange for development as soon as possible.

Plates, or film, which are to be transported to hot and humid climates, as in the tropics, should be ordered in sealed metal container. Practically all manufacturers are in a position to supply their negative materials in a special packing for tropical use at a nominal expense.

Types of Color Sensitive Materials.—The variation in sensitivity with the wave length of the radiation to which the film, or plate, is exposed is termed spectral or *color* sensitivity. There is a wide variation among negative materials in this respect; however, it is usual to consider all photographic materials designed for use in the visible region as belonging to one of three classes: (1) *ordinary,* or blue-sensitive, (2) *orthochromatic,* or less frequently, *isochromatic* and (3) *panchromatic.*

1. *Blue-sensitive Materials.* The spectral sensitivity of materials of this class ends at a wave length of approximately 500 millimicrons as shown in Fig. 156. Materials of this type, therefore, respond only to violet and blue, and are practically insensitive to such visually brilliant colors as green, yellow, orange and red. In this class belong all films and plates which are not rendered sensitive to radiation of longer wave lengths through the addition of a sensitizing dye. (See p. 146.) This includes all developing papers, lantern slides and transparency plates and films and many medium and high speed negative materials.

2. *Orthochromatic and Isochromatic Materials.* Photographic materials sensitive to yellow as well as to violet and blue are termed *orthochromatic,* i.e., true color, or *isochromatic,* i.e., equal color. Orthochromatic or isochromatic plates and films are practically insensitive to radiation of wave lengths longer than 600 millimicrons: they do not respond, therefore, to spectral orange or red. However, since most

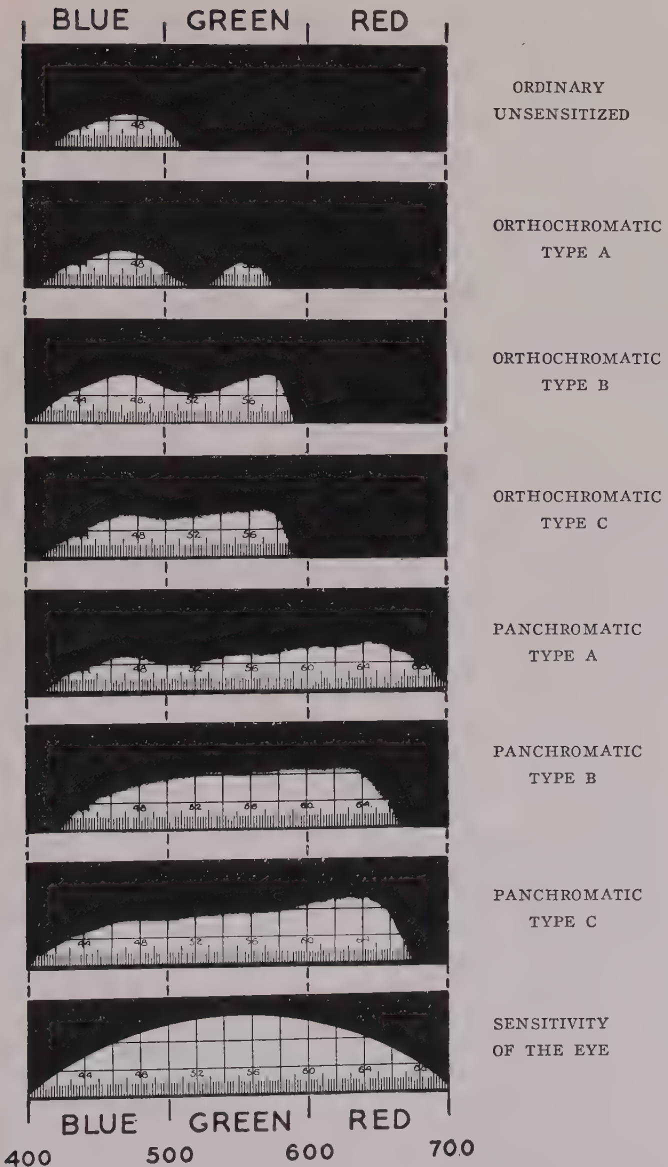

FIG. 156. Spectrograms of Different Types of Color Sensitive Materials (Tungsten Light) (Eastman Kodak Co.)

natural reds reflect some green and yellow, red is rendered lighter than with a blue-sensitive material.

Orthochromatic materials now available may be divided into three types which may, for convenience, be termed Ortho A, Ortho B, and Ortho C (Fig. 156).

Orthochromatic plates and film, having a relatively low sensitivity to green, are included in type *A*. Erythrosin was used almost exclusively until comparatively recently as a sensitizer for othochromatic materials. Consequently, most orthochromatic plates and films introduced prior to 1930 are of this type. It is less powerful than later sensitizers and particularly noticeable for the low sensitivity in the green within the wave length of 550 millimicrons.

The discovery within recent years of new and more effective orthochromatic sensitizers has made it possible to produce materials much more sensitive to green and yellow than were possible with Erythrosin. Materials of medium green sensitivity (Fig. 156) are classified as type *B*, and those of high sensitivity to green as type *C*. It will be noted that with the newer dyes, the depression in sensitivity within the wave length of 550 millimicrons has become less, almost completely disappearing with type *C* materials.

3. *Panchromatic Materials.* Photographic materials sensitive to radiation through the entire visual range are termed *panchromatic*, i.e., all color.

Panchromatic materials differ considerably as respects the distribution of sensitiveness throughout the spectrum and may be divided into three classes designated as *A*, *B* and *C*. Spectrograms showing the spectral sensitivity of these classes are shown in Fig. 156.

1. Type *A*. To this class belong all materials sensitized with pinacyanol, or isocyanine or carbocyanine dyes in use prior to 1931. Materials of this type are being replaced steadily by those of types *B* and *C* in which the total sensitivity, as well as the sensitivity to long wave radiation, is greater.

2. Type *B*. Panchromatic materials of this type have been termed *ortho-panchromatic* because, except for a maximum point of sensitivity in the blue-violet, their distribution of sensitivity is similar to that of the eye.

3. Type *C*. Materials of this type have been termed *hyper-panchromatic* because of their high general sensitivity throughout the visible region. Panchromatic materials described as supersensitive or hypersensitive belong in this class.

Infra-Red Sensitive Materials.—The sensitivity of the eye ends at a wave-length of approximately 700 $\mu\mu$. Beyond this, lies the invisible infra-red. Recent advances in the dye sensitizing of photographic materials has made it possible to record spectral lines having a wave-length of approximately 1300 $\mu\mu$. Most of these infra-red sensitive materials are of interest only to the scientist;[2] however, materials of the type represented by the spectrograms in Fig. 157 are of general interest as with them it is possible to make photographs of ordinary subjects by means of infra-red radiation instead of light. Materials of this type are now sufficiently sensitive to permit of instantaneous exposures on out-door subjects under favorable conditions. A red filter is required to absorb the blue light to which these materials, in common with all photographic materials, are sensitive. An infra-red filter is required only if the visible light is to be absorbed, as when making pictures in total darkness.

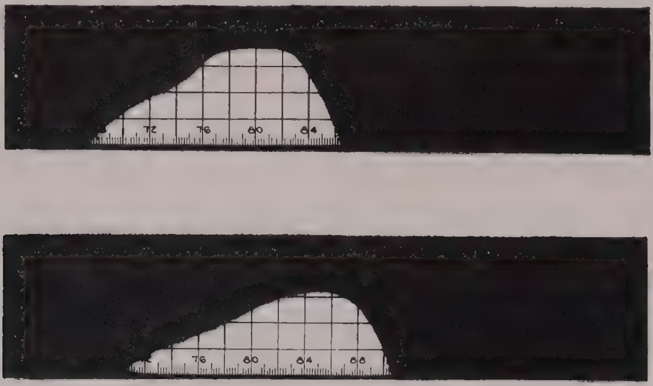

Fig. 157. Spectrograms Showing the Distribution of Sensitivity of Two High Speed Infra-red Materials Designed for General Photography

Infra-red photography is employed chiefly for the purpose of eliminating atmospheric haze and securing sharper definition and contrast on distant objects. The scattering effect of haze is at a maximum in the ultra-violet and becomes less and less as the wave-length increases. Thus the use of a yellow filter and an orthochromatic material or better yet a red filter and a panchromatic material in place of an ordinary blue-sensitive material will result in greater penetration of the haze and produce sharper and clearer images of distant objects.

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[2] Mees, Photographic Plates for Use in Spectroscopy and Astronomy, Eastman Kodak Co., 1938.

The difference is still more marked in photographs made wholly by the invisible infra-red rays.

Infra-red photographs of landscapes present a number of striking differences from those made in the usual way. The sky and the shadows are dark because of the absence of reflected infra-red radiation. Green foliage, on the other hand, appears nearly white due to the fact that chlorophyl reflects the infra-red rays in sunlight strongly. Advantage is frequently made of this effect to produce pictures which appear to have been made by moonlight.

Non-Halation Materials.—The halo which frequently surrounds the image of bright objects in the picture is known as *halation.* It is due to the reflection of light from the rear of the emulsion support as shown in Fig. 158. A part of the ray of light penetrating the emulsion layer is scattered in all directions by the grains of silver halide. This scattering of light by the emulsion is known as *irradiation* and is generally negligible except in cases of great overexposure or great enlargement of the image.

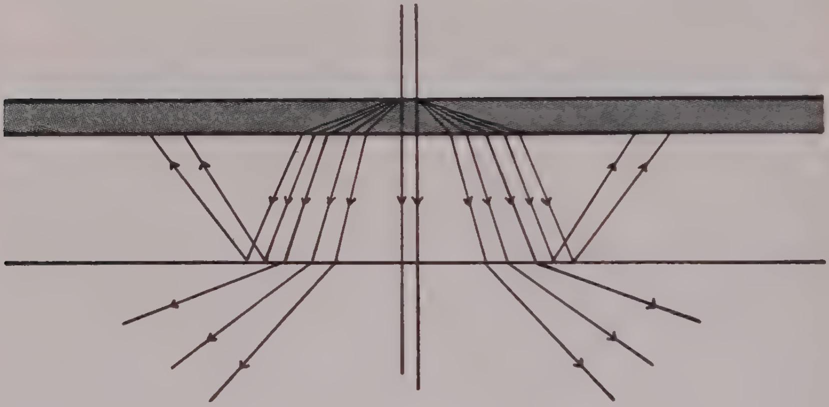

FIG. 158. Diagram of Halation

However, not all of the light entering the emulsion layer is scattered; some is absorbed producing the latent image and, since an emulsion is semi-transparent, some is transmitted and upon being reflected back into the emulsion from the rear surface of the glass, or film base, produces the halo which is termed halation.

The intensity of the halo depends upon a number of factors, namely:

1. *The amount of exposure:* The greater the exposure the more intense the halo.

2. *The turbidity and thickness of the emulsion:* The greater the turbidity, and thickness, of the emulsion the less light it transmits and, therefore, the lower the intensity of the halo. A thickly coated plate, or film, is much less subject to halation than a thinly coated one.

3. *The method of development:* Methods of development which act chiefly on the surface, or in the upper layers of the emulsion, develop less of the halo than those which act deeply.

Photographic materials designed to prevent halation are appropriately termed *non-halation* or *anti-halation.* The methods employed to achieve this end may be conveniently grouped under four heads:

1. *Placing a Light-Absorbing Layer, or Backing on the Rear Surface of the Glass or Film Base.* Backed plates have been an article of commerce almost as long as the dry plate itself and the value of backed plates in dealing with subjects in which halation is likely to occur is well established. In recent years, backings containing dyes which are decolorized in the developer, or fixing bath, and require no attention in processing have largely replaced the older backing materials which contained a pigment in a water soluble material, such as dextrine or caramel, which had to be removed during development by washing in running water and discolored the developer so that it could no longer be used.

2. *Placing a Light-Absorbing Layer Between the Emulsion and the*

HEBBEL—Halation on Plates and Films. Photofreund., **10** (1930), 404, 461.

KUSTER—An Objective Method for the Determination of Halation. Phot. Korr., **71** (1935), 65, 73; S.&I.P. (II), **6** (1935), 363.

MAUGE—Examination and Measurement of Halation. Bull. Soc. Franc. Phot., **14** (1927), 12–30.

NEUGEBAUER—Halation Tests. Photofreund., **9** (1930), 452.

RHEDEN—Halation and Its Prevention. Phot. Rund. **4** (1926), 69–79.

FARBENINDUSTRIE A.-G.—Anti-Halation Backing for Plates and Films. F.P., 747, 539, 14.12.32; G.P., 570, 991, 16.12.31; S.&I.P. (II), **5** (1934), 324. B.P. 416,198 (15.10.32).

FARBENIND.—Anti-Halation Layer Composed of Manganese Dioxide. F.P. 778,934 (5.10.33). S.&I.P., **7** (1936), 381.

RENWICK AND KING—Anti-Halation Coatings for Photographic Supports. B.P. 421,721 of 31.5.33.

SCHNEIDER—Filter Layer. (Agfa Ansco Corp.) U.S.P. 2,036,546 of 24.2.33.

SLACK—Non-Halation Photographic Film. (Eastman Kodak Co.) U.S.P. 2,036,440 of 18.2.31.

Support. The backing in this case consists of a dye, or an opaque salt, which is decolorized by the developer.

3. *Increasing the Amount of Light Absorbed in the Emulsion by Double Coating.* This has long been popular in the United States where the majority of cut films intended for professional use are double coated; first with a slow, blue-sensitive emulsion and then with the regular negative emulsion. The emulsion next to the support ordinarily plays no part in the formation of the image. It is designed to be as opaque as possible and its only function is to absorb light transmitted by the emulsion coated over it.

4. *Increasing the Opacity of the Film Base.* For motion picture work, a soluble backing is not desirable and instead a grey base film in which the backing is an integral part of the film base is used. The increased density of the negative is compensated for by increase in exposure when printing.

Sensitive Materials for Portraiture.—Sensitive materials for portraiture must have a long scale of gradation, high speed, reasonably fine grain and medium contrast. Both ordinary (blue-sensitive) orthochromatic and panchromatic materials are in use but color sensitive materials are to be preferred over ordinary or blue-sensitive materials because of the superior rendering of flesh values (which eliminates a large amount of the retouching necessary with blue-sensitive materials), the improved color rendering of the hair, eyes, lips and dress colors and lastly the higher speed when artificial light is employed. High speed orthochromatic materials are preferred by many especially when clear tungsten lamps are employed as producing better rendering of skin textures than panchromatic materials and permitting development by a red safelight.

Ortho-panchromatic and hyper-panchromatic materials are widely employed, however, with photoblue and clear tungsten lamps, electric arcs as well as with daylight. In Fig. 159 are shown comparative photographs of a typical portrait subject on blue-sensitive, high speed orthochromatic, and ortho-panchromatic materials with incandescent clear tungsten illumination.

Sensitive Materials for Press Work.—Films and plates for press work must be of high speed, for much press work must be done under unfavorable light conditions. In addition, materials for press work should develop rapidly and produce contrast readily, have fine grain and be physically hard to withstand forced processing and drying. Both ordinary (blue-sensitive) orthochromatic and panchromatic ma-

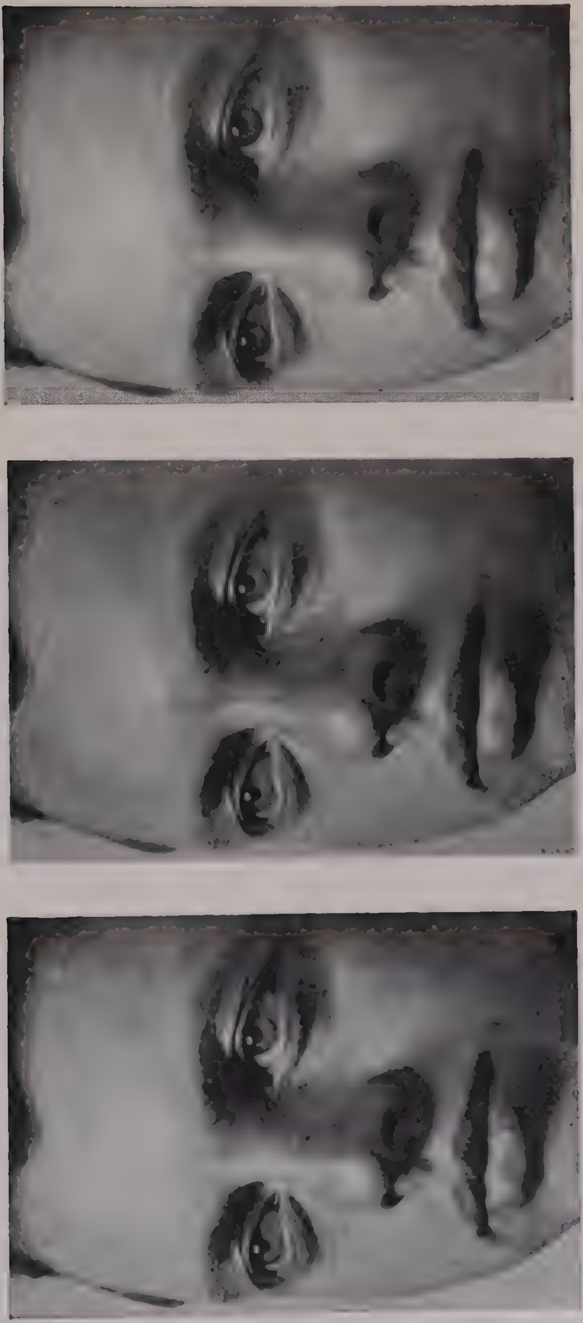

Fig. 159. Rendering of Flesh Values on Different Types of Photographic Materials

Left—Ordinary blue sensitive material Center—Orthochromatic material Right—Panchromatic material Tungsten illumination terials are in general use with the tendency towards the two last mentioned due to their greater speed with tungsten illumination. Both plates and cut film are in general use although it would appear that glass plates will in time be superseded by film on account of its lesser weight, freedom from breakage and general convenience.

Sensitive Materials for Process Work.—Films and plates designed for photographing line subjects must work free from fog, have high resolution, that is, be able to separate fine lines, and produce high contrast. Sensitometrically such a material is represented by a characteristic curve having a steep straight-line portion, a high maximum density, and a short toe, or underexposure, portion.[3]

Ordinary (blue-sensitive) materials are suitable for line subjects in black and white, but for colored objects either orthochromatic or panchromatic process materials must be used.

Special films of this type for the lithographer, offset and process worker have been introduced in recent years under such trade names as Kodalith, Reprolith, etc. As compared with the so-called process material, these require from 5 to 10 times as much exposure, have a finer grain, higher resolution and produce greater density when developed in special hydroquinone-paraformaldehyde developers. Materials of this type are coated on a thin base film which may be printed from either side so as to render stripping and transposition of the image unnecessary, or on paper with a soluble layer between the paper stock and the emulsion so that the image may be stripped and transferred (strip-film).

Document papers coated with emulsions of the process type are employed in copying machines such as the Photostat or Rectigraph for making copies of printed matter, documents, plans, etc. without an intermediate negative.

Materials for Landscape Photography.—In general, color sensitive materials are preferred for landscape photography although for the atmospheric effects of early morning or later afternoon, ordinary (blue-sensitive) materials are favored as emphasizing the effect of mist. However, if the proper rendition of the colors of the subject, or of clouds is desirable color sensitive materials are a necessity. Since brilliant reds are rare in the average landscape, orthochromatic materials are suitable although equally satisfactory results are obtainable on panchromatic materials with lighter filters and usually with less exposure.

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[3] Higson, "The Emulsion for a Process Plate," *Phot. Jl.*, **59** (1919), 266.

For distant views, mountains, scenery, and in aerial photography, panchromatic materials with a strong yellow or orange-red or red filter are required (page 247). Still greater penetration of haze is obtained through the use of infra-red sensitive materials and suitable filters.

Sensitive Materials for Commercial Photography.—Commercial photography covers an exceedingly wide range of subjects and no one type of sensitive material is suitable for all. In general, however, color sensitive materials which produce density and contrast readily are preferred. For still-life subjects, a rapid film or plate is not required; suitable color sensitivity, fine grain and the ability to obtain brilliant negatives of comparatively high contrast are more important.

Orthochromatic film with a yellow filter is suitable, for example, for light wood such as oak, satinwood, walnut, unfinished mahogany, etc., but for finished mahogany, a panchromatic material and orange-red filters are required. Tapestries, decorated china and all similar colored objects generally require a panchromatic material and a suitable filter.

In copying sepia prints those which are yellow stained as a result of age or imperfect fixation, a panchromatic material of the so-called "commercial" variety is required. In the first case, a fully correcting filter should be used: in the second, a strong yellow contrast filter.

Maps, blue-prints, plans in color, etc., require a process panchromatic material and a suitable filter.

For architectural subjects, a medium speed orthochromatic or panchromatic material with a light yellow filter is usually preferred. If the building is light colored and outlined against the sky, strong yellow, or orange-red filters may be required. In dull light, the appearance of old brick buildings may be greatly improved by using a slow panchromatic plate or film and an orange-red filter.

Since extremes of contrast and bright reflecting surfaces are frequently met with in commercial subjects, films and plates which are backed or double coated to reduce halation are advisable in many cases.

Fine Grain Materials.—The growth in the popularity of the miniature camera during the past decade has been due quite as much to the development of fine grained emulsions as to the appeal of the small camera itself. Modern fine grain emulsions have in reality made the miniature camera practical, for without emulsions of this type, users of small cameras would be restricted necessarily to comparatively small pictures. Modern fine grain emulsions are the result of intensive research directed towards the attainment of a finer grained emulsion without the sacrifice of speed or other desirable characteristics and the discovery of more efficient color sensitizers which have made possible the production of sensitive materials of high speed without necessitating a corresponding increase in grain size.

Both orthochromatic and panchromatic fine grain materials are available with the latter predominating on the American market. In speed, the fine grain films available are only slightly inferior to the most rapid negative materials. They tend to yield negatives of greater brilliance particularly in the shadows than other rapid negative materials and frequently the time of development is less.

Direct Copy Film.—It is, of course, well known that great overexposure of any negative material will produce a reversed image, i.e., a negative from a negative or a positive from a positive. Reversal is facilitated by general exposure to light or by the incorporation of fog producing substances such as sodium arsenite, permanganates, persulfates and dichromates in the emulsion. With ordinary negative materials, the reversed image obtained through overexposure is so poor in quality as to be of no practical value. Recently, however, a special direct copy film has been introduced,[4] which upon exposure and development in the usual manner produces images of good contrast and gradation.

As the speed is approximately the same as slow contact printing paper, it is too slow for use in the camera; however, it is well adapted to making duplicate negatives either by contact or projection, to making duplicate transparencies or other cases in which a direct copy image is required.[5]

Safelights for Negative Materials.—A safelight is a color screen which, when used in conjunction with a suitable light source, provides illumination by which a particular sensitive material may be handled with reasonable safety. To this end it must, as far as is consistent with a suitable visual intensity, transmit only illumination within the wave length region to which the emulsion is least sensitive. Any safelight then is necessarily a compromise between two conflicting requirements, maximum safety and maximum visibility which last depends upon the amount of light transmitted and its wave length region.[6]

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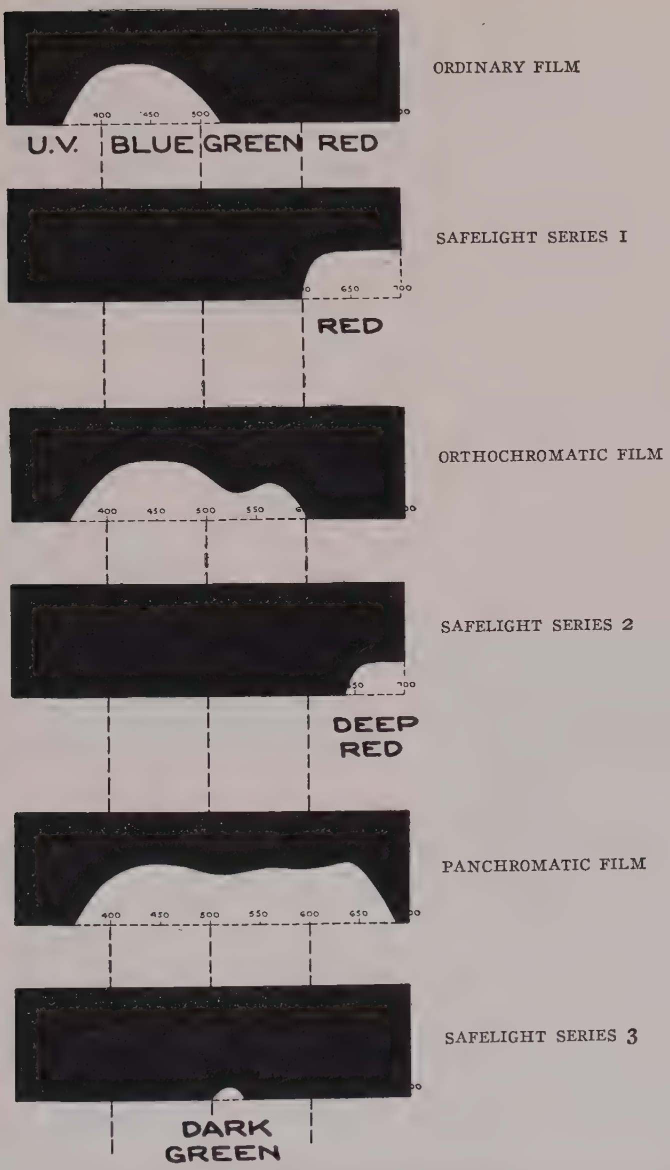
[4] Agfa-Ansco Corporation.

[5] Arens, H. & Eggert, J., Agfa. *Veroeffentl,* III (1934), p. 166. Arens, H., U.S.P. 2,005,837 (1935). Barth, W., *J. Soc. Mot. Pict. Eng.,* 27 (1936), p. 419.

[6] Mees & Baker, *Phot. Jl.,* 47 (1907), 276. Chilton, *Phot. Jl.,* 71 (1931), 226.


ORDINARY FILM

SAFELIGHT SERIES 1

ORTHOCHROMATIC FILM

SAFELIGHT SERIES 2

PANCHROMATIC FILM

SAFELIGHT SERIES 3

FIG. 160. Safelight Color and Negative Sensitivity (Eastman Kodak Co.)

A safelight transmitting red only is satisfactory for blue-sensitive and medium speed orthochromatic materials since both are practically insensitive beyond a wave length of 550 millimicrons (Fig. 160). With high-speed orthochromatic materials a safelight transmitting only the extreme red (Fig. 160) provides a greater margin of safety without too great a sacrifice in illumination.

Panchromatic materials are sensitive throughout the visible spectrum so that it is obviously impossible for any safelight transmitting any part of the visible spectrum to be really safe. The problem in designing a safelight for such materials is to obtain the maximum visibility with the smallest possible amount of light. The eye is not equally sensitive throughout the spectrum and at low intensity levels the blue-green region affords the maximum visibility for a given amount of light. Hence, while the film or plate is sensitive to light throughout the spectrum, an amount of blue-green light which is sufficient to see by may be used with a reasonable degree of safety. To secure the same visibility in the red would require a stronger source of illumination which would lead to fog.

The sensitiveness of super-sensitive and hyper-sensitive panchromatic plates and film is so great that no light which is of any real value visually is safe while the emulsion is dry. When partly developed, its sensitiveness is lower and the safelight may then be used for momentary inspections of the developed image without serious danger of fog. It is much better, however, to handle such films and plates in total darkness.

The standard of safety adopted for the products of at least one manufacturer of screens is that no effect should be produced on the plate when it is exposed to the safelight at a distance of one meter for thirty seconds. Most screens will produce fog if rapid or highly color-sensitive plates are exposed to their action for much over a half minute. A good working test of safety is to place a plate facing the safelight and about two feet away and expose part of it for thirty seconds, leav-

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Chilton—Efficiency of Safe Lights for Dark Room Use. Phot. J., **71** (1931), 226–233.

Mees and Baker—Measurement of the Efficiency of Darkroom Light Filters. Phot. J., **47** (1907), 276.

Trivelli—Lights for the Darkroom. Brit. J. Phot., **58** (1911), 474, 494, 533, 628, 777, 872, 957; **59** (1912), 22.

ing part of the plate unexposed by covering it with several coins, or a piece of black paper. If the plate shows signs of fog, after development in total darkness for the usual time, the light is unsafe for the plate and either a weaker light source should be used, the plate handled at a greater distance from the lamp, or the safelight should be changed to one which more nearly transmits light to which the plate is insensitive.

CHAPTER XI

PHOTOGRAPHIC EXPOSURE

Theory of Exposure.—Photographic exposure is defined as the product of time and intensity of illumination acting upon the photographic material. A series of exposures may be produced, therefore, by a variation in either the time of exposure or the intensity of the illumination. When a photographic material is exposed in the camera, the time factor is constant and the variation in exposure for different parts of the image is directly proportional to the brightnesses of the corresponding parts of the subject, except for variations due to the absorption and scatter of light in the lens.

Usually, the essential requirement is that the photographic record of these brightnesses create the visual impression of the original subject. It is, however, only within a certain exposure range that a sensitive material is able to record differences in brightnesses correctly. Strictly speaking, this range in exposure is indicated by the straight-line portion of the D-log E curve of that particular film or plate. In practice, however, portions of the curve at both extremities of the straight-line portion may be used without producing evident falsification of brightness values.

The problem in exposure, therefore, is to adjust the time factor so that the exposures produced by the various brightnesses of the subject are within the exposure range which produces a satisfactory reproduction of the subject on the plate or film employed.

Factors Influencing the Time of Exposure.—The time of exposure depends on (1) the brightnesses of the image on the photographic material and (2) the sensitivity, or speed, of that material.

The brightnesses of the image are determined by:

1. *The intensity of the light on the subject.* The intensity of sunlight is determined by the time of day, time of year and by the presence of clouds or other atmospheric disturbances.

While with long experience the eye may acquire the ability to distinguish differences in illumination under conditions with which it is familiar, in general the eye is a poor judge of the intensity of illumination, unless aided, nor is it able to evaluate the variations in color which affect exposure. Hence, such classifications as intense light, bright light, light clouds, dull, etc., while helpful, are only approximations.

However, since the subject is not always fully exposed to the direct light of the sun or the sky, its location may have an important bearing on the illumination which it receives. In a narrow street, for example, the illumination is greatly reduced by the buildings on either side which permit light from only a small strip of the sky to reach the subject. Likewise in heavily wooded areas or in shaded places, under porches and the like, the illumination is greatly reduced. It is extremely difficult to estimate the illumination visually under such conditions and while it is possible to make some allowance for the subject factor by classifying the more common subjects into groups, more errors in exposure probably result from the difficulties arising from this source than from any other.

2. *The amount of light reflected from the subject.* Subjects differ greatly in the proportion of the light falling on them which is reflected. A subject containing only water and sky, for example, reflects a larger proportion of the light falling on it than does a distant landscape, and this in turn more than a landscape in which are figures, trees, shrubbery, buildings or other dark colored objects near the camera. In general, the nearer the subject is to the camera the larger the shadow areas and the less the amount of reflected light.

In evaluating the amount of light reflected, or the brightness, the quality of the light, or its color, must be considered with particular reference to the color sensitivity characteristics of the photographic material. The more nearly the color response of the film or plate approaches that of the eye the less the difficulty experienced in evaluating the allowance to be made for the color, or colors, of the subject.

3. *The light transmitted by the lens.* This, for all practical purposes, is proportional to the relative aperture or f :number.

Exposure Meters.—There are essentially two types of exposure meters: (1) those which measure the intensity of the light on the subject by the rate of darkening of a sensitive paper and (2) those in which the light reflected from the subject is measured by visual methods or by means of a photo-electric cell. Meters of the first type (actinometers) were the first to find general acceptance; they have been replaced almost completely in recent years, however, with instruments of the second class and in particular those employing photo-electric cells.

Actinometers.—Among exposure meters of this type, the best known, in English speaking countries at any rate, are the Watkins and the Wynne. Both are made in watch form and utilize the darkening of sensitive paper to a standard tint which, however, differs in the two meters. The meter is held to face the light illuminating the darkest part of the subject and the time for darkening of the paper to the standard tint is determined. This time, the actinometer time as it is called, is an indication of the intensity of the light and from it the exposure required with a given lens aperture and plate or film is calculated with the aid of the movable scales which form a part of the instrument. In the case of the Watkins meter, the first visible darkening of the sensitive paper requires 1/16 of the time necessary for the standard tint; hence indoors, or where the light is poor, the time required for making a test of the light may be reduced by using the sixteenth time as it is called.

The weak point of the actinometer is that it can measure only the light falling on the subject and not that reflected from it. However, if the proper allowance is made for different subjects, the exposure indications of an actinometer produce a high percentage of satisfactory results.

Visual Exposure Meters.—Instruments of this type may be divided into two classes: (1) those in which the subject is viewed through an optical wedge, which for convenience is usually circular, and this is revolved past the eye until detail in the shadows disappear or are barely visible. The proper exposure is then determined from the scales of the instrument at this setting. Typical meters of this last class are the Heyde, the Ica Diaphot and the McMurtry. (2) In the second place are meters in which the light reflected from the subject illuminates an artificial test object, usually a transparent figure, the visibility of which may be reduced in a measurable manner by means of an optical wedge or an adjustable diaphragm. In some examples a number of figures varying in visibility are seen when the meter is pointed at the subject and the number just barely discernible is taken as a measure of the light reflected from the subject. The advantage of meters of this type over those described in class one is in the certainty with which the extinction point can be determined. On the other hand with meters of this class when used at the camera, it is the average brightness of the subject which is measured and not that of

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Gundelfinger and Stafford—Photometric Determination of Camera Exposures for Motion-Picture Work. J. Franklin Inst., **215** (1933), 81.

a particular part of the subject as with meters of class one. The total brightness of the subject may or may not be a satisfactory indication of the proper exposure. If, for example, a large portion of the subject is brightly illuminated and the shadow area is small, an exposure based upon the total amount of light reflected by the subject may result in underexposure of the shadow areas. All meters which measure the total amount of light are open to this objection which, however, may be overcome to some extent if the shadow area can be approached so as to exclude the remainder of the subject in making the measurement.

In all visual type meters it is the visual brightness of the subject which is measured and not the actinic brightness, which may be quite different. The eye and photographic materials differ considerably in their response to different colors, therefore, the visual brightness is not an accurate indication of the exposure required in the case of an object involving color. In most meters, this difficulty is partially overcome by the insertion of a blue-violet screen in the field of vision. Visual measurements of brightness then correspond more nearly with the actinic brightness, but this expedient naturally fails to take into consideration the differences in photographic materials with respect to color sensitivity.

The accuracy of meters in which brightness is measured by the extinction of detail in the subject or an artificial test object are affected by the ability of the eye to adjust itself to variations in the intensity of illumination over a fairly wide range. Thus on coming into a darkened room the eye soon adjusts itself to the weaker illumination and we shortly begin to see detail that was totally invisible when we entered the room. Consequently, the exposures indicated by the meter will not accurately represent the real difference in the intensity of the illumination on the two subjects. The result is that another correction factor has to be applied to the meter readings of interior work.

Meters of this type have been made to measure the brightness of the image or the focusing screen but have never found general acceptance.

Photocell Meters.—In recent years, exposure meters employing light sensitive photocells have come into general use. While not a complete solution of the exposure problem, such instruments affording as they do a convenient and accurate means of measuring illumination are of very real assistance in determining exposures.

Light sensitive cells have been available for a number of years but the amplifying tubes, batteries and control devices required in their operation made them too involved and bulky for use in exposure meters. The self-generating photocell perfected in 1930 is entirely electronic in action; radiant energy striking the cell is transformed directly into electrical energy. The current generated is directly proportional to the intensity of illumination on the cell over a considerable range (Fig. 161); hence, it is possible to measure brightness directly without reference to the eye from the electrical output of the cell as indicated on a suitable microammeter. As there is no physical or chemical change in the sensitive material composing the cell, its life is believed to be practically unlimited.[1]

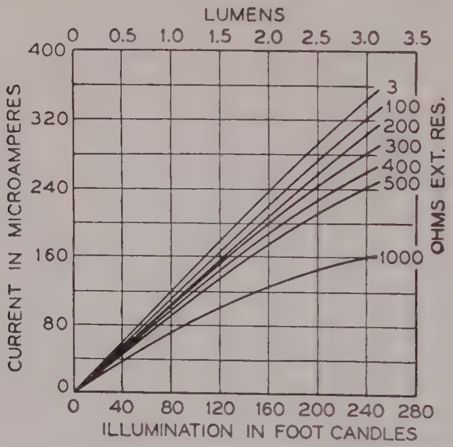

FIG. 161. Curves Showing the Relation Between Current Output and Illumination on Photronic Cell (Lamb, *Electrical Engineering,* 1935)

The color sensitivity of the photocell is similar to that of the eye (Fig. 162), but extends farther into both the red and the ultra-violet. The response of the cell to violet and blue is relatively greater than that of the eye but not so great as that of photographic materials. It would be possible by means of suitable filters to make the response of the cell practically identical with that of the eye. This has not been done in any existing exposure meter.

There is little difference fundamentally in the photocells used in the different meters, but the angle from which light is allowed to reach the cell and the scales provided for the computation of the exposure vary greatly. The usual practice is to restrict the light reaching the cell by means of apertures, tubes, or lenses to an angle approximately equal to that included by the average lens. Meters designed for use with still cameras include an angle of from 50 to 70 degrees and some of the older types a still wider angle.

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[1] Goodwin, *J. Soc. Mot. Pict. Eng.,* 20 (1933), 95.
Harrison, *Phot. Jl.,* 74 (1934), 172.

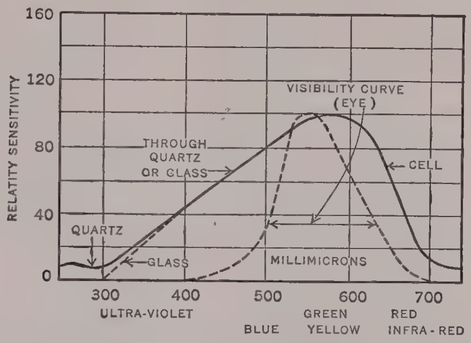

FIG. 162. Curve Showing the Spectral Sensitivity of the Photronic Cell Compared with the Eye (Lamb, *Electrical Engineering,* 1935)

The angle included by any meter may be further restricted by the addition of a projecting hood. The masking effect of the hood should be determined by making a brightness measurement of a large uniformily lighted surface with and without the hood.

Use of Photocell Exposure Meters.—In most cases, it is sufficient to measure the average brightness of the entire scene from a point near the camera by holding the meter so that it receives only the light reflected from the subject. Out-of-doors, care should be taken not to include too much of the sky or the brightness measurement may lead to underexposure. If the subject is one which is generally well lighted, but contains dark objects near the camera, an exposure based on the average brightness of the scene may lead to underexposure of the darker portions. On the other hand, with a subject which is generally dark but contains a well lighted area, the latter may be overexposed. With such subjects, it is best to measure the brightness of that portion of the subject which is the most important. This may be done by making the measurement from a position which is sufficiently close to include only the light reflected from the area in question. The angle included by the cell varies in different meters but generally if the distance from which the measurement is made is approximately equal to the shortest dimension of the area, whose brightness is to be measured, the results will be sufficiently accurate for practical purposes.

The brightness which can be lowest accurately measured varies slightly with different meters but is usually on the order of one foot-candle. The brightness of objects too dark to be measured directly may often be determined as follows: First measure a portion of the object having the same general tone on which the illumination is sufficient for a measurement to be made. Then measure the brightness of a sheet of white paper placed in the same position. The ratio of the two brightnesses gives the reflection coefficient of the paper. Then place the paper in the darker area and measure the light reflected by the paper. Divide the value thus obtained by the reflection coefficient of the paper and use the brightness value thus obtained in calculating the exposure.

Latitude in Exposure.—The difference in the range of exposures over which a negative material can reproduce differences in brightness satisfactorily and the exposure or brightness range of the subject constitutes what is termed *exposure latitude.* Latitude in exposure, therefore, depends upon the latitude of the sensitive material (page 208) and the exposure or brightness range of the subject. The latitude in exposure accordingly increases as the brightness range of the subject becomes less or as the latitude of the sensitive material increases. The latitude of most negative materials is considerably greater than the range of brightnesses in the average subject with normal illumination. Whereas the brightness range of the average subject is usually not more than 1 to 50 and frequently less (page 209) the latitude of a good negative material is not less than 1 to 200 and frequently as much as 1 to 500. It is evident, therefore, that the exposures may vary considerably without exceeding the limits imposed by the latitude, or exposure scale, of the sensitive material Were it not for this latitude the problem of exposure would be difficult indeed.

Exposure Required to Stop Motion.—The amount of displacement possible in the image of a moving object without producing visible unsharpness depends upon the allowable circle of confusion (page 89). In general, it is customary to regard as allowable a circle of confusion equal to 1/1200 of the focal length of the lens. If, however, the image is to be greatly enlarged, a still smaller circle of confusion is necessary.

The amount of the displacement of the image of a moving object in a given time interval depends upon four factors:

1. *The velocity of the object.* The displacement of the image is obviously proportional, other factors being constant, to the velocity of the moving object. Usually this is unknown but in certain cases it may be estimated with sufficient accuracy for practical purposes. One knows for example, within certain limits what speed to expect of runners at the finish of any of the usual distances, of horses coming down the home stretch, and in many other athletic and sporting events. It must be remembered that allowance must be made for the more rapid movement of the arms and legs which move approximately twice as fast as the body itself.

2. *Distance of object from camera.* The nearer the moving object is to the camera the larger the image and the greater the displacement for a given exposure. Except for very short distances the displacement of the image for a given exposure is inversely proportional to the distance of the object.

3. *The focal length of the lens.* For a given object distance the longer the focal length of the lens the larger the image and the greater the displacement of the image in a given time interval. Thus the displacement of the image under given conditions, varies directly with the focal length of the lens.

4. *Direction of movement.* With an object moving in a direction at an angle to the optical axis of the lens, the displacement of the image is the sum of the displacement due to the lateral movement of the object and the movement in line with the axis.

The time of exposure permissible in the case of an object moving at right angles to the optical axis of the lens is indicated by the equation

$$E = \frac{D + F}{S \times 100F}$$

where E = Exposure in fractions of a second,
F = Focal length of lens in inches,
D = Distance of object at time of exposure in inches,
S = Speed of objects in inches per second,
100 = Denominator of fraction indicating allowable circle of confusion.

For practical purposes this may be written

$$E = \frac{D}{S \times 100}.$$

For an object moving directly to or from the camera the equation is

$$E = \frac{(D + F)^2}{S \times 100FX(A + 2)},$$

in which E, D, S, and F have the same significance as in the previous equation and $(A + 2)$ represents the depth of the object in inches.

For an object moving at an angle to the optical axis of the lens, the permissible exposure is given by

$$E = \frac{D + F}{S \times 100F \times \cos\theta} \div \frac{(D + F)^2}{S \times 100F \times (A \div 2) \times \sin\theta}.$$ [2]

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[2] Cleveland, *Amer. Phot.*, 1925, p. 386, 442. See also Cummings, *Brit. J. Phot.*, 70 (1923), 447.

CHAPTER XII

THEORY OF DEVELOPMENT

Development as a Process of Chemical Reduction.—The operation by which the invisible, or latent, photographic image is made visible is known as development. Since the exposure required to produce a visible image is many times that required to produce an image which may be made visible by development, the latter is in effect a means of multiplying the result produced by light so that an almost infinitesinal exposure of the sensitive silver halide grain may be converted into a substantial image.

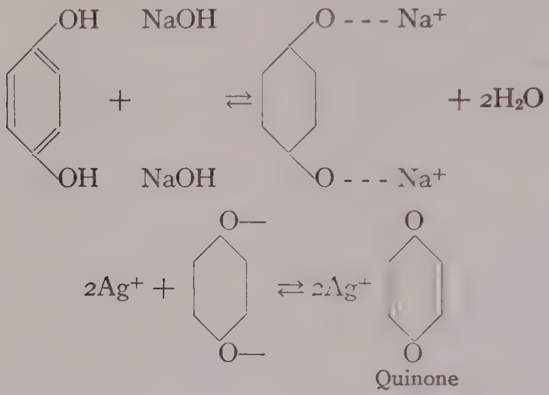
If the latent photographic image is regarded as consisting of minute nuclei, or centers, of silver on the grains of silver halide affected by light, development consists essentially in the formation of sufficient additional silver about these nuclei to produce a visible image. The added silver required to produce a visible image may be the result (1) of preferential deposition of silver from a silver-containing solution (the so-called "physical" development), (2) or the reduction of the grains of silver halide containing a nucleus (i.e., exposed grains) to silver ("chemical" development). While it is possible that negative development involves both types to a limited extent, only the latter phase will be discussed here.

Chemical development is thus a process of chemical reduction and consists in the conversion of ionic to metallic silver. The reaction may be represented as $Ag^+Br^- + Redc = Ag + Ox + Br^-$; in other words, there is an exchange of ions between the ionized silver halide and the developing agent. The silver cation receives an anion from the developer which removes its positive charge, and it becomes metallic silver. The bromine anion is fixed in the form of an organic, or metallic, bromide depending upon the nature of the developing agents. Owing to the complex constitution of the organic developing agents, it is difficult to be more precise on this point. The one reducing agent whose action may be said to be fully understood is ferrous oxalate, the reaction in this case being

$$Ag^+ + Fe\ (C_2O_4) = Ag\ (metal) + Fe\ (C_2O_4).$$

Among the common organic developers, alkaline hydroquinone used without sulphite, is the only one which has been extensively studied. According to Sheppard, the reaction is as follows:

Development with hydroquinone[1]:



More difficult to explain is the selective reduction of the silver halide that is, the ability of the reducing agent, or developer, to distinguish between exposed and unexposed silver halide. If the latent image is regarded as consisting of centers, or nuclei, of silver on the silver halide grains, there are at least three ways in which these specks or nuclei of silver might promote selective reduction:

1. By acting as a center for the deposition of the silver formed by reduction of the silver halide, thus lowering the concentration of the silver within the grain and allowing the reaction to proceed until the entire crystal of silver halide is converted to metallic silver.

2. The developing substance may be adsorbed to the silver of the latent image, but not to silver bromide. This would produce a high concentration of the ionized developing agent in the neighborhood of the nucleus, and result in the adjacent silver halide being reduced, whereupon more developer would be adsorbed, converting more of the silver halide to silver, the process continuing in this manner until the crystal of silver halide is completely converted to metallic silver.

3. The silver of a nucleus may act as a catalyzer in the reduction of the silver halide by the developer, favoring the reduction of the exposed grains of silver halide over the unexposed.

The Rate of Reduction.—There are three phases in the process of development: (1) the induction phase, (2) the reduction phase, (3) the precipitation phase.

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[1] Sheppard, *J. Chem. Ed.*, 4 (1927), 754.

Beginning with the surface of the emulsion layer, the developer rapidly diffuses through the gelatin and then more slowly penetrates the crystal of silver halide. This is followed by the progressive reduction of silver halide to silver, and the addition of silver thus formed to the original nucleus a process, which assuming a constant supply of fresh developer, continues until the crystal is completely developed.

Diffusion plays a very important part in these reactions, and other things being equal, those crystals lying nearest to the surface of the emulsion layer will be penetrated and attacked first. Since, the strength of the developer is being continually reduced by use, the development of the lower strata of silver halide grains will be delayed until the concentration of fresh developer is sufficient to initiate and complete the reduction of the silver halide. Consequently, in the development of negative emulsions, or emulsions of any considerable thickness, it is probable that all three phases of the developing process are taking place at the same time.

De Langhe—Theory of Photographic Developability. Z. wiss. Phot., **35** (1936), 201.

Evans and Hanson—Photographic Development and the Latent Image. Phot. J., **77** (1937), 497.

Homolka—The Latent Image and Development. Brit. J. Phot., **64** (1917), 81.

Matthews and Barmeier—The Electro-potentials of Certain Photographic Developers and a Possible Explanation of Photographic Development. Brit. J. Phot., **59** (1912), 879.

Murray—A Theory of Photographic Development. Phot. J., **77** (1937), 388.

Pandalai—Mechanism of Photographic Development. J.S.C.I., **54** (1935), 169T.

Rabinowitsch—The Mechanism of Development. J. Phys., **5** (1934), 232. S.&I.P. (II), **5** (1934), 250.

Rabinovitch—Theories of Photographic Development. Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 295.

Sheppard—The Electro-chemistry of Development. Trans. Electrochem. Soc. (1921), 429.

Sheppard and Elliott—On the Theory of Development. Trans. Faraday Soc., **19** (1923), 355.

Sheppard and Mees—Some Points in Modern Chemical Theory and their Bearing on Development. Phot. J., **45** (1915), 241.

Volmer—The Theory of Development of the Latent Photographic Image Zeit. wiss. Phot., **20** (1921), 189; Phot. Korr. (1921), 226.

The time elapsing between the application of the developer and the first appearance of the image is known as the induction period and corresponds with the arithmetical coefficient of development. The induction period, with any particular developer, is a constant fraction of the time required for a given degree of development, but this arithmetical relationship is altered by soluble bromides and iodides, the former lengthening and the latter shortening the induction period.[2]

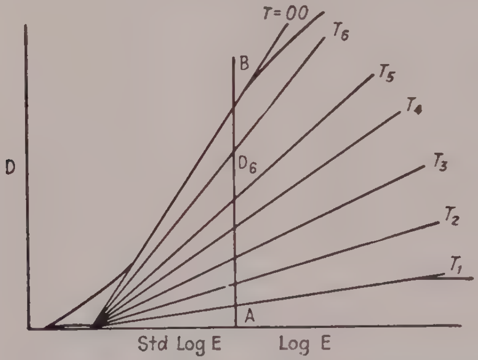

FIG. 163. Growth of Density with Time of Development (Nietz)

If, for a given exposure, the variation in density with the time of development is found by erecting a perpendicular from a point on the log exposure axis, so as to intersect the straight-line portions of a family of H and D curves (Fig. 163) and density is plotted as a function of the time of development, a curve of the exponential type (Fig. 164) is obtained. This indicates that the growth of density is rapid at first, becoming slower and slower as development proceeds until the latent image is completely developed when it ceases, except for the increase due to the development of unexposed silver

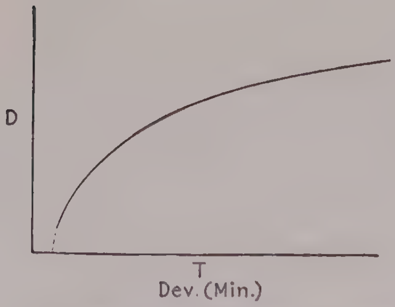

FIG. 164. Curve Showing Growth of Density with Time of Development (Nietz).

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[2] Sheppard, *Phot. Jl.*, **45** (1905), 281; Sheppard, *J. Chem. Soc.* (London), **87** (1905), 1311; Sheppard and Meyer, *Phot. Jl.*, **60** (1920), 12.

halide (fog). The maximum density obtainable (*D* Max) depends chiefly upon the emulsion, but varies to some extent with different developers.

The explanation of this progressive diminution in the velocity at which density increases is quite simple, although it is a difficult matter to find a mathematical expression which will cover all conditions.

After development for any length of time short of that required to produce the maximum density, three kinds of grains are present:

A. Developed grains.
B. Developable but undeveloped grains.
C. Undevelopable grains.

The *A* grains represent the density already attained; the *A* and *B* grains together, the maximum density which can be secured exclusive of fog. The *B* grains, therefore, are the only ones subject to development and as the reaction proceeds the number of *B* grains will become less and less until finally when all are developed the process must stop. Thus the density undeveloped at any time t will be $(D_\infty - D)$, where D is the density developed at any time t and D_∞ the maximum density. Supposing that the rate at which the developer reduces the exposed, but undeveloped grains, is a constant and independent of the number of grains (as is actually the case) and that the rate of diffusion remains unaltered, we can express the rate of development, or dD/dt as

$$\frac{dD}{dt} = k(D_\infty - D),$$

where k is a constant determined by the rate at which the exposed grains are reduced by the developing agent. This formula fits the case fairly well with acid developers over a moderate range but wide variations are observed with most alkaline developers and other more

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Davidson—Conditions Governing the Behaviour of Silver Bromide Grain During Development. II. Phot. J., **66** (1926), 230–242.
Krohn—The Mechanism of Development of the Image in a Dry Plate Negative. Phot. J., **58** (1918), 179; Brit. J. Phot., **65** (1918), 412.
Luppo-Cramer—Topographical Relations in Development. Z. wiss. Phot., **24** (1926), 1–12.
Nietz—Theory of Development. Phot. J., **60** (1920), 280.

complex equations have been suggested to account for the various factors involved.[3]

The constant K is termed the *velocity constant* of development. With any particular emulsion and developer, at a particular temperature, the value of K is a direct indication of the rate of development.

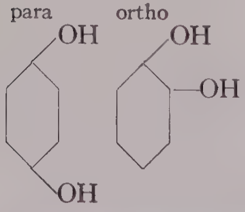
To determine the value of the velocity constant, k, the values of gamma for two sensitometric strips simultaneously exposed and developed for different times, of which one is double the other must be known. The values of γ^1 and γ^2 having been found, k may be calculated from the following equation:

$$k = \frac{I}{t_1} \log e \frac{1}{\gamma^2 - \gamma^1} \quad \text{or} \quad \frac{I}{t} \log_e \frac{D_\infty}{D_\infty - D},$$

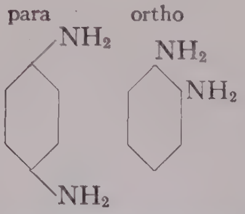
where D_∞ = maximum density, D density at time t.[4]

Developing Agents.—Comparatively few reducing agents are suitable as photographic developers. To be suitable for use as a developer, a reducing substance must be able to distinguish between exposed and unexposed silver halide; in other words, the reducing energy (*reduction potential*) must be such that the latent image is developed before an appreciable amount of unexposed silver halide is reduced to silver. Many reducing agents are so powerful that they reduce unexposed silver halide to silver (eg. triaminophenol); the reducing energy of others is too low to be useful practically (e.g. ferrous citrate); still others (hydrazine for example) cannot be used because of undesirable reaction products. While a number of inorganic substances function as developers,[5] the developing agents in use today are all para or ortho diphenols, diamines or aminophenols as follows:

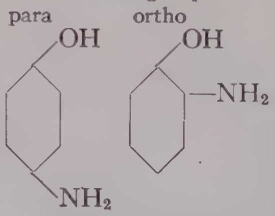
Diphenols
Two—OH groups



Diamines
Two—NH_2 groups



Aminophenols
One—OH+one
—NH_2 group



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[3] A comprehensive review of later work on the velocity of development and development velocity equations will be found in *The Theory of Development*, by A. H. Nietz.

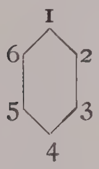
[4] Mees and Sheppard, *Phot. Jl.*, **43** (1903), 48; **44** (1904), 297.

[5] Hydrogen peroxide (Andresen, 1889); alkaline ferro-oxalates (Carey Lea, 1877); hyposulfites (Eder, 1886) and vanadates (Lumiere, 1894).

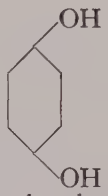
While there is some evidence to show that developing properties do not depend on the constitution of the reducing agent but simply on its reduction potential[6] the work of A. and L. Lumiere, Seyewetz and Andresen has established certain general rules which apply to the organic developing agents known.

Compounds containing two hydroxyl (OH); two amino (NH_2) or one hydroxyl and one amino group.

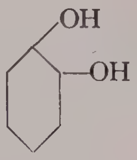
1. These substances are developers only if the groups occupy the 1 and 4 (*para*) or the 1 and 2 (ortho) positions in the benzene nucleus. For example:



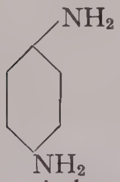
Benzene



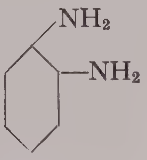
parahydroxybenzene
(hydroquinone)



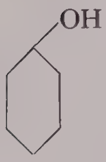
orthohydroxybenzene
(pyrocatechin)



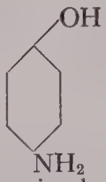
Paraminobenzene



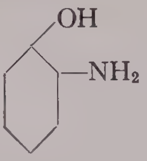
Orthoaminobenzene



Phenol



Paraminophenol



Orthoaminophenol

2. Substances in which the two substituted groups occupy the 1 and 4

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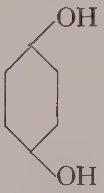
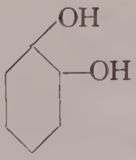
[6] Maurer and Zapf, *Phot. Ind.*, **33** (1935), 90; Abribat, *Phot. Jl.*, **75** (1935), 434.

ANDERSEN—Organische Entwicklersubstanzen. Eder's Jahrb., **7** (1903), 486.
LUMIERE AND SEYEWETZ—Developing Properties of *m*-Derivatives. S.&I.P., **8** (1928), 37.
SEYEWETZ—The State of our Knowledge of Organic Developing Agents. Bull. Soc. franc. Phot. (1920), 129; Brit. J. Phot., **66** (1920), 186.
SEYEWETZ AND SZYMSON—Products of Oxidation of Photographic Developers by Silver Bromide. II. Bull. Soc. chim. **1** (1934), 1506.

or *para* position are more energetic developers than ortho (1 : 2) compounds. For example:

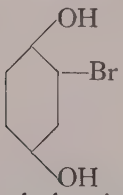


is more powerful than



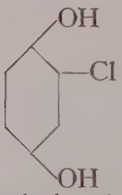
3. The dioxybenzenes are more energetic developers than the aminophenols, and these in turn are more energetic than the diaminobenzenes.

4. The substitution of chlorine or bromine for hydrogen in the benzene nucleus increases the developing energy. For example:



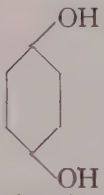
Bromhydroquinone

or



Chlorohydroquinone

are more active than



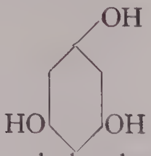
Hydroquinone

5. The substitution of acid groups such as (COOH, SO_3H, etc.) for hydrogen in the benzene nucleus lowers the developing energy.

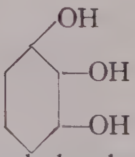
6. Developers with two hydroxyl groups (para and ortho hydroxybenzene) require an alkali. Developers with one hydroxyl and one amino group (paraminophenol, orthoaminophenol will develop without an alkali but are not practical when so used.

Compounds containing more than three active groups (OH, NH_2).

1. Substances containing three groups with a symmetrical arrangement (1 : 3 : 5) are not developers. No definite rule appears to apply to other groupings. For example:

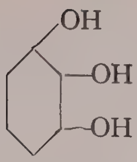


1 : 3 : 5 hydroxybenzene
(not a developer)

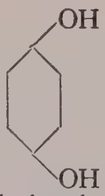


1 : 2 : 3 hydroxybenzene
(Pyrogallol)

2. The energy of developing agents containing three hydroxyl or amino groups is greater than that containing two such groups. For example:



is more energetic than

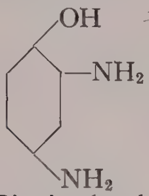


1 : 2 : 3 hydroxybenzene
(Pyrogallol)

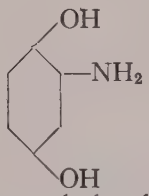
Parahydroxybenzene
(Hydroquinone)

3. Compounds containing three hydroxyl groups (Pyrogallol) can develop without an alkali but are not practical unless used with an alkali.

4. Increasing the number of amino groups increases the developing energy. For example:



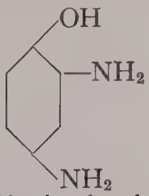
is more powerful than



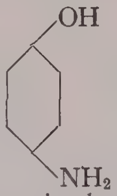
Diaminophenol

Monoamino parahydroxybenzene

5. If the developer contains three or more hydroxyl and amino groups, the energy is greater without an alkali than with a developer containing only two such groups. For example:



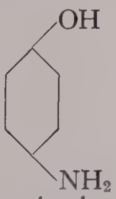
is more energetic without an alkali than



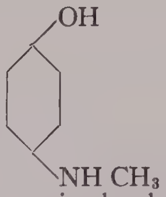
Diaminophenol

Paraminophenol

7. The energy of a benzene derivative which is already a developer is increased by the introduction of a methyl CH_3 group. For example: The energy of



is increased by the replacement of one H of the NH_2 by CH_3



Paraminophenol

Monomethylparaminophenol (Metol)

The maximum reducing energy is obtained when the group is in the ortho position with respect to a hydroxyl.[7]

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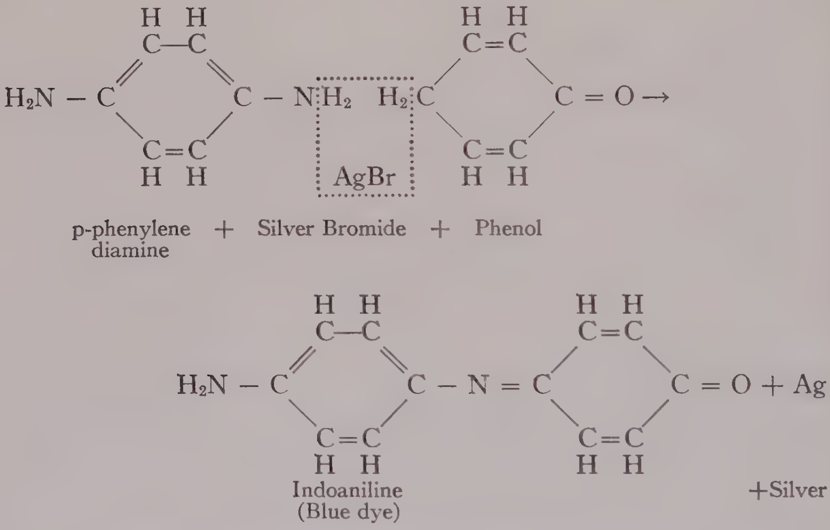
[7] Seyewetz, A., *Le Negatif en Photographie,* 2d ed., p. 164.

Color Developers.—A number of organic substances act as developers, producing an image consisting of finely divided silver and a dye which is the result of the oxidation of the developer in the reduction process. A comparatively large number of developers of this type are known, among them thioidoxyl, alpha naphthol, and 1:4 dioxy-iso-quinolin, although the most prominent, due to the investigations of Homolka, is indoxyl,[8] but have found little application in practice.

In 1912, Fischer[9] found that phenol and certain of its derivatives when combined with a suitable developing agent, such as paraphenylene or paraminophenol, is reduced in the process of development to an indophenol or azine dye, thus resulting in the formation of an image of silver and a colored dye.

The reaction taking place may be represented schematically as follows:[10]



The developing agents which function in this manner are termed color developers and the dye-forming substances *color formers.*

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[8] Homolka, *Brit. J. Phot.,* **54** (1907), 136, 196, 216; *Phot. Korr.,* **51** (1914), 256, 471; Ermen, *Brit. J. Phot.,* **70** (1923), 47, 299.

[9] Fischer, *Brit. J. Phot.,* **60** (1913), 595, 712; (1914) 329. U.S.P. 1,055,155, 1,079,757, 1,162,028.

[10] Davies, *Phot. Jl.,* **76** (1936), 251.

The subject of color developers has received considerable attention in recent years because of their application to natural color photography,[11] and three processes of color photography utilizing color developers, namely Kodachrome, Agfacolor and Gasparcolor, are now in use commercially.

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[11] Consult patent specifications on color photography in *Photographic Abstracts* (Royal Photographic Society of Great Britain).

CHAPTER XIII

DEVELOPING SOLUTIONS

Characteristics of the Principal Developing Agents.—*Diaminophenol* (*Amidol*). Diaminophenol is one of the few developing agents in general use which does not require an alkali. With sodium sulfite alone it forms an energetic, soft-working developer which is employed chiefly for the development of bromide papers. Solutions of diaminophenol deteriorate rapidly and generally are inactive in from two to three days even if kept in tightly closed vessels. Deterioration is not accompanied by any marked change in color; hence, the appearance of the solution is no indication of its condition. The keeping properties of solutions of diaminophenol may be improved slightly by the addition of boric acid,[1] glycollic [2] or lactic [3] acid or tin chloride.[4]

Hydroquinone (*Hydrochinon, Hydrokinone, Quinol*). Hydroquinone, a developing agent of low energy, is quite sensitive to bromide and other restrainers, and its activity is greatly reduced by low temperatures, so much so that it is practically inert below 50° F. (10° C.). In negative development, the highlights appear first, then the middle tones and lastly the shadows. The tendency, therefore, is towards density and contrast rather than detail.

Hydroquinone is used alone chiefly for work in which extreme contrast and density are required. It may be used with either the alkaline carbonates or the caustic alkalis, although the latter are preferred for the highest possible density and contrast, while for certain materials, the use of para formaldehyde is recommended.

[1] Namias, *Prog. Foto.*, 1921, 45.
[2] Crowther, *Brit. J. Phot.*, **67** (1920), 642.
[3] Bunel, *Bull. Soc. Franç. Phot.*, 1921, 290.
[4] Desalme, *Brit. J. Phot.*, **68** (1921), 359.

DRUCE—Stabilizing Solutions of Amidol. Brit. J. Phot., **69** (1922), 81.

BRAMER AND ZABRISKIE—Production of Hydroquinone. (Eastman Kodak Co.) U.S.P. 1,998,177 of 25.4.34.

LOBEL AND BUNEL—Developer Containing Diaminophenol and p-Phenylenediamine in Bisulphite Solution. Bull. Soc. Franc. Phot., **13** (1926), 143–147.

For general purposes, it is usually combined with metol (monomethyl paraminophenol).

Chloro- or Brom-Hydroquinone (*Chloroquinol, Adurol*). As developers these substances are similar to hydroquinone but are more energetic, particularly at low temperatures, are less sensitive to bromide and other restrainers, and have less tendency to fog and stain. For negative development, they are usually used in combination with metol.

Glycin (*Athenon*). As a developer, glycin is slow but powerful. It is especially notable for the fine grain of the reduced silver and the freedom from any tendency to fog even in the absence of an alkaline bromide. Unlike other organic developing agents, glycin is not directly oxidized by air and does not produce a stain image. It keeps well in solution and is especially suited to continuous use in tanks. Glycin is frequently used in combination with metol, with paraphenylenediamine (in fine-grain developers) and with hydroquinone for obtaining warm-black tones on chloro-bromide papers.

Monomethylparaminophenol (*Metol, Elon, Rhodol, Photol*). Metol alone, or in combination with hydroquinone, has been one of the most popular of all developers since its introduction by Hauff in 1891. It is a rapid, soft-working developer which is only slightly affected by the presence of bromide or other restrainers. It has a long useful life, and used alone it will develop a larger amount of sensitive material before becoming exhausted than any other agent.

While metol will develop without an alkali, it is generally used with the alkaline carbonates, although borax and other alkalis are employed for special purposes. At times, it is difficult to secure sufficient contrast with metol alone; hence, it is usually combined with hydroquinone. Other popular combinations are metol-glycin and metol-pyro.

Paraminophenol. The free base is only slightly soluble in water; hence, the hydrochloride or sulfate is generally employed. When used with the alkaline carbonates, paraminophenol forms a rapid, soft-working developer which is notably free from any tendency to produce development fog even at temperatures considerably above normal.

Ermen—Rodinal Type Developers. Brit. J. Phot., **67** (1920), 611.

Gray—The Preparation of Concentrated Developing Solutions. Brit. J. Phot., **80** (1933), 175.

Schering—Benzyl Para-amidophenol Compounds as Developers. British Patent, 20,050 (1907).

Willcock—Concentrated Phenolate Developers. Brit. J. Phot., **83** (1936), 256–257.

Paraminophenol is for this reason especially suitable for high temperature development.

Highly concentrated paraminophenol developers of exceptional keeping properties may be prepared by adding paraminophenol hydrochloride or sulfate to a solution of potassium metabisulfite and adding sufficient sodium hydroxide to dissolve the precipitated free base. Developing preparations of this type have been available commercially for years; among the better known are Rodinal, Azol, and Actival.

Paraphenylenediamine. The developing properties of paraphenylenediamine were discovered by A. and L. Lumiere and A. Seyewetz who recognized its value as a fine-grain developer.[5] The fine grain is due (1) to its solvent action on silver halide and (2) its low reduction potential. These two factors prevent full development of the latent image thus necessitating an increase in exposure as compared with more energetic developers such as paraminophenol and diaminophenol. It is possible that development with paraphenylene diamine is largely of the character associated with physical development in which silver is deposited on the latent image from a silver-bearing solution.

The silver deposit is dichroic, i.e., black by transmitted light and cream-colored by reflected light so that a thin negative frequently appears positive by reflected light. The printing density, however, is greater than the visual density so that negatives which appear to be lacking in density and contrast may be of good printing quality.

The free base, $C_6H_4(NH_2)_2$ is slightly alkaline and may be used without an alkali; the hydrochloride, $C_6H_4(NH_2)_2 \cdot 2HCl$, however, is acid and must be used with an alkali in order to develop. The

[5] *Bull. Soc. franç. Phot.,* **20** (1904), 422.

Bramer and Ruggles—Process for Preparing Metol. Kodak Ltd. B.P. 435,721 (10.11.33).

Ermen—Preparation of Monomethyl Paramidophenol Sulphate (Metol). Phot. J., **63** (1923), 223.

Hubl—Metol-Quinol Developer. Phot. Rund., **63** (1926), 481–487.

Reinders and Beukers—Metol-Hydroquinone Developers. Phot. J., **74** (1934), 78.

Lehmann and Tausch—Chemistry of Metol-Quinol Development. Phot. Korr., **71** (1935), 17, 35.

Tschibissoff and Tschelzoff—Chemistry of Developers and Development. II. Metol-Quinol Developers and Metoquinone. Kinotech., **11** (1929), 315–321.

Whitaker—Manufacture of Monomethyl Para-Aminophenol and its Sulphate. (Industrial Dyestuff Co.) U.S.P. 1,993,253 of 18.9.34.

hydrochloride oxidizes less readily than the free base and is more soluble in cold water although less so in hot water. Both keep well in the dry state if protected from the air.

Paraphenylenediamine (free base) is supplied under many trade names such as Paramine, Diamine, Diamine P. Dianol, etc., and the hydrochloride as P.D.H. Diamine H. etc. Both are toxic and produce painful skin eruptions on those susceptible. For those affected by paraphenylene, the use of rubber gloves appears to be the only preventative.

Pyrogallol. Pyrogallol has been in use longer than any other organic developing agent; however, it has a number of disadvantages which cause it to be used less and less. It oxidizes readily and the yellow oxidation product stains the gelatin so that the useful life of a pyrogallol developer is short. In development the oxidation taking place in the reduction of the exposed silver halide to metallic silver results in the formation of a stain image. Most developers produce a stain image but with none of the common developing agents is the stain image as intense as with pyrogallol. Its existence can be demonstrated by reducing a portion of a pyro developed negative in Farmer's reducer. This removes the silver image, leaving a yellow image which is composed of the oxidation product formed in the process of development. The intensity of the stain image depends on the amount of sodium sulfite or other preservative used, the amount of solution exposed to air, the temperature, and the degree of agitation. It is difficult to control all these factors precisely, and therefore, the intensity of the stain image; hence, since the density and contrast of the negative vary with the stain image, it is difficult to secure as uniform results with pyrogallol as with other developing agents.

Pyrogallol is usually employed with the alkaline carbonates as an alkali; in the presence of diaminophenol, however, pyrogallol is capable of developing without an alkali.[6]

[6] Hall, *American Photography,* 1922, 326; Bunel, *Bull. Belge Phot.,* 44 (1922), 151.

LOWE—Paraphenylenediamine: Free Base or Hydrochloride? Zeiss Magazine, 2 (1936), 43, 58, 75 and 78.

WEINLAND—*p*Phenylenediamine—the Chemical. Camera (Phila.), 49 (1934), 145.

SEYEWETZ—Use of o-Phenylenediamine for the Development of Fine-grain Images. Bull. Soc. Franc. Phot., 23 (1936), 159.

Pyro is a very flexible developing agent, much more capable of modification than some of the agents which have largely replaced it. With concentrated solutions, strong contrast may be obtained while with more dilute solutions and a lower concentration of alkali, soft, delicate results are produced. Pyro is perhaps most often used alone; frequently, however, it is combined with metol or with gylcin.

Minor Developing Agents.—The following developing agents are (1) little used, (2) used only for special purposes or (3) are no longer available commercially.

Edinol. As a developer, Edinol, is similar to metol but less energetic. It is noticeably free from staining and fogging tendencies. It may be used alone, but is more generally employed in combination with hydroquinone. It is now seldom employed except by those whose skin is affected by metol.

Eikonigen. This developer is no longer available commercially, having been replaced by metol which it resembled in many respects, its principal differences being its lower energy, higher rate of oxidation, and more rapid exhaustion in use.

Ortol. Used alone, ortol bears a close resemblance to pyro, not only as respects the color of the image, which is brownish-black, but in the progressive appearance of the image. As with pyro, the highlights appear first, followed by the half-tones, and lastly the shadows. This gradual building up of the image is quite different from the action of metol and other rapid developers in which the highlights, half-tones, and shadows appear at very nearly the same time, and density is built up later. Ortol, unlike pyro, however, does not stain and keeps much better in solution.

Pyrocatechin (*Kachin*). Pyrocatechin is a more energetic developer than hydroquinone, to which it is closely related chemically. It differs from other common organic developing agents in retaining its normal developing power in the presence of hypo. This property has caused it to be used in processes of combined developing and fixing. It is now little used.

JACOBSOHN—Properties of the Pyrogallol Developer. Kinotech., **II** (1929), 76.

SCHULTES—New Developers Derived from Pyrogallol. Phot. Ind., **34** (1936), 896; S.&I.P., **7** (1936), 344.

SEYEWETZ—Combination of Developers of Phenolic Function with those of Amine Function. New Combination of o-Phenylenediamine and Pyrocatechol. Bull. Soc. Franc. Phot., **23** (1936), 253.

Metoquinone and Chloranol. These are two introductions of A. and L. Lumiere.[7] Metoquinone is a chemical combination of methylparaminophenol (metol) and hydroquinone and chloranol a combination of paraminophenol and chloro-hydroquinone. Unlike the parent substances both develop without an alkali. In this and many other respects, they are similar to diaminophenol, but unlike it are quite stable in use. Except for Lumiere products, such as the Lumiere Autochrom, neither is in general use. Pyramidol a condensation product of paraminophenol and hydroquinone, was introduced by Hauberrisser. It was similar to paraminophenol and is no longer available commercially.

Duratol, Monomet, Neol, Hydramine. These are all no longer obtainable. Duratol (Benzyl paraminophenol) was introduced by Schering in 1910 as a substitute for methylparaminophenol, as was monomet (paraminothocresol hydrochloride) introduced by the White Band Company in 1916. Neol (paraminosalicylic acid) was introduced by Hauff in 1918 as a compensating developer permitting the correction of considerable overexposure.[8] Hydramine, a condensation product of hydroquinone and paraphenylene diamine, was introduced by A. and L. Lumiere in 1899.[9]

Solubility of Developing Agents.

Agent	Solubility in Water at 60° F. (15° C.)	Solubility in 5% Na_2SO_3 and Na_2CO_3
Diaminophenol	1 in 4	
*Edinol	15.9 gm. per liter	9.7 gm. liter
*Eikonigen	7.6 “ “ “	8.2 “ “
*Glycin	0.23 “ “ “	12.8 “ “
*Hydroquinone	5.7 “ “ “	7.4 “ “
*Metol	4.8 “ “ “	4.5 “ “
Ortol		
*Paraminophenol (base) HCl	33.0 “ “ “	3.2 “ “
*Pyrocatechin	33.3 “ “ “	35.7 “ “
*Pyro	52.4 “ “ “	41.8 “ “
Paraphenylenediamine		

* Kail, *Phot. Korr.*, 1921, Festnummer.

Keeping Properties of Developers in Solution.—The keeping properties of a developing solution depend upon the developing agent, the concentration of sulfite, and in certain cases, as with pyrogallol, the acidity of the solution. No investigations of the rate of oxidation with different developing agents using a constant concentration of sulfite appear to have been made. Milbauer [10] studied the rate of oxidation of various developing agents using typical formulae. The order of stability was found to be as follows: glycin (best), chloro-hydroquinone, metol, eikonigen, ortol, hydroquinone, diaminophenol and lastly pyrogallol.

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[7] *Bull. Soc. franç. Phot.*, 1903, 231.

[8] B.P. 154,198 of 1918. Luppo-Cramer, *Phot. Korr.*, 1920, p. 270.

[9] *Bull. Soc. franç. Phot.*, 1899, 135.

The rate of deterioration of developing solutions was studied also by Hubl [11] who placed the different agents in the following order: metol-hydroquinone (best), glycin, pyrocatechin, chloro-hydroquinone, metol, hydroquinone, and lastly pyrogallol.

The Relative Reducing Energy of Developing Agents.—The relative reducing energy, or reduction potential, of the different developers has been measured in various ways, but chiefly by the depression in density produced by a given concentration of soluble bromide.[12]

Taking the bromide concentration required to produce a given density depression with hydroquinone as unity, Nietz obtained the following values as representing the reduction potentials of some of the developing agents.

p-phenylene diamine hydrochloride (no alkali)	0.3
p-phenylene diamine hydrochloride (with alkali)	0.4
Hydrochinon	1.0 (Standard)
p-phenyl glycin	1.6
p-amidophenol (hydrochloride)	6.0
Chlorohydrochinon (adurol)	7.0
Monomethyl p-aminophenol sulphate (metol)	20.0
Diamidophenol (amidol)	30–40

Differences among Developing Agents with Respect to Treshold Speed.—The various developing agents differ in the minimum light exposure rendered visible upon development. Of the common organic developing agents, methylaminophenol (elon, metol, etc.) results in the highest threshold speed and pyrogallol, the lowest. In general, the order in which developing agents are placed in this respect is the same as their reduction potential and it is possible that there is some connection between the two.[13]

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[10] *Phot. Korr.*, p. 682.

[11] *Entwicklung der photographischen Bromsilbergelatineplatten,* W. Knapp Halle a/S 1922.

[12] Bredig, *Eder's Jahrbuch,* 9 (1895), 19. Sheppard and Mees, *Investigations on the Theory of the Photographic Process,* Longmans Green, London, 1903. Nietz, *Theory of Development,* D. Van Nostrand Co., New York, 1922.

The difference between developing agents is largely independent of the composition of the developer. The differences are more marked in the case of process and positive materials than with those of higher speed.

Differences in Developing Agents as Respects Fogging Properties.—The fog characteristic of a developer may be defined as the ratio of the rate at which the image is developed and that at which fog appears.[14]

The fog characteristic depends upon so many factors that it is difficult to determine values for the developing agents directly except under certain narrowly defined conditions which in many cases are not directly applicable to those of practical photography. In general, however, it may be said that there appears to be no connection between the fog characteristic and the reduction potential of a developing agent. Thus hydroquinone, pyro, metol and diaminophenol represent a series with increasing reduction potential, but with fogging tendencies in the reverse order.[15] Paraminophenol is exceptionally free from any tendency to produce fog even at high temperatures. According to Scheberstow, it has the lowest fog ratio of any of the organic developing agents in general use. It is probable that the fogging tendencies of some developing agents are increased by the impurities found in the commercial product and by oxidation products which in some cases tend to produce fog.[16]

Mees and Piper found that fog is practically independent of the concentration of alkali—a conclusion at variance with the commonly accepted opinion—but increases rapidly with an increase in the concentration of sulfite up to a maximum, which varies with different developing agents. Beyond this point, the increase is slight. The tendency of a developer to produce fog almost invariably increases with the dilution owing to the increased oxidation which results in aerial or oxidation fog.[17]

[13] Bullock, *Sci. Ind. Phot.*, 6M (1926), 33, 41; 7 (1927), 5, 9.

[14] Scheberstow, *Sci. et Ind. Phot.*, 6 (1935), 298.
Shiberstoff, *Bull. Soc. franç. Phot.*, 22 (1935), 209.

[15] Nietz, *Theory of Development*, D. Van Nostrand Co., New York, 1922.

[16] Crabtree, "Chemical Fog," *American Annual of Photography*, 1919.

[17] Mees and Piper, 51 (1911), 226; 52 (1912), 221.

Dundon and Crabtree—Fogging Properties of Developers. Brit. J. Phot., 71 (1924), 701, 719.

Differences in Developing Agents with Respect to Rate of Exhaustion.—With all developing agents, there is a loss in activity with use. This loss in activity affects development in two ways: (1) longer development is required to reach a given degree of contrast or gamma, and (2) the lower densities are less fully developed tending to produce the effect of underexposure.

The effect of repeated use on density with different developing agents using a standard formula was investigated by Strauss who found that[18] metol has the longest useful life, followed in order by paraminophenol, edinol, ortol, chloro-hydroquinone, glycin, pyrocatechin and, much worse than the others, pyro.

Ermen investigated the exhaustion of developers using the time of appearance on developing papers.[19] His results placed the different developing agents in the following order: metol (best), dimethylaminophenol, paraminophenol, metol-chlorohydroquinone, chloro-hydroquinone, and lastly hydroquinone.

The Preservative.—All organic developing agents have a strong affinity for oxygen; it is necessary, therefore, to add to developing solutions a preservative to lessen the rate of oxidation, thereby preserving the developing agent and preventing the formation of colored oxidation products which stain the gelatin.

Sodium sulfite, desiccated (Na_2SO_3) is the preservative in general use in this country; in England, and to a limited degree elsewhere, the crystal form ($Na_2SO_3 \cdot 7H_2O$) is employed. Practically, one part of the former is equivalent to two parts of the latter. The corresponding potassium and ammonium salts are rarely used.

Sodium sulfite is occasionally replaced wholly, or in part, by sodium bisulfite ($NaHSO_3$) an acid sulfite which in an alkaline developer is converted into sodium sulfite and sodium bicarbonate. Developers containing bisulfite give slightly less fog than those containing sulfite only, but the reason for this is unknown.

The manner in which a developing agent is protected from oxidation by a sulfite is somewhat obscure, but it appears probable that the sulfite combines with the developing agent to form a complex sulfonate of the developer which is oxidized less readily in the presence of oxygen than either the developing agent or the sulfite alone.

According to Rzymkowski,[20] the first stage in the oxidation of a developer containing sulfite by the oxygen of the air is the formation of a sulfate and a thiosulfuric acid derivative of the developing substance, R–S–SO_3H, which is then hydrolysed to the hypothetical compound R–SOH. The easily oxidizable SOH group is selectively converted to the sulfonic group SO_3H, and in this manner the active groups of the developing substance are protected from oxidation.

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[18] *Phot. Ind.*, 1925, 309.

[19] *Brit. J. Phot.*, **68** (1921), 64.

[20] *Phot. Ind.*, **26**, 1928, 627.

Sulfite in protecting the developing agent from oxidation reduces the colored substances formed by the oxidation of the developing agent to colorless substances, so that the oxidized products of the developing agent in the presence of sulfite are not the same as when the sulfite is absent.

The quantity of preservative employed varies greatly; among the factors determining the amount required are:

1. *The susceptibility of the developing agent, or agents, to oxidation.* Developing agents vary considerably in resistance to oxidation, ranging from pyrogallol, which in an aqueous solution is completely oxidized within a few hours, to glycin which is oxidized only very slowly. The more readily the developing agent accepts oxygen from the air, the greater the amount of preservative required for satisfactory keeping properties in solution.

2. *The concentration of the developer.* The amount of preservative required for a dilute developer is greater than for a more concentrated solution because the proportion of the developing agent to the available oxygen is less, thus rendering necessary an increased amount of the preservative to insure satisfactory keeping properties.

3. *The temperature at which the developer is kept.* The rate of oxidation increases with the temperature; consequently, a developer used at a temperature above normal requires a larger amount of preservative.

Evans and Hanson—Reduction Potential and Photographic Developers: The Effect of Sulphite in Developer Solutions. J. Phys. Chem., **41** (1937), 509.

Pinnow—Behaviour and Function of Sulphite in Developing Solutions. P. Rund., **60** (1923), 27.

Rao and Pandalai—Sodium Sulphite in Developing Solutions. Nature, **131** (1933), 100.

Rzymkowski—Behaviour of Sulphite in Photographic Developers. Phot. Ind. (1928), 627.

Weinland—Sodium Sulphite—the Chemical. Camera (Phila.), **52** (1936), 289.

Schiel—Sodium Sulphite in Developers. Phot. Rund., **65** (1928), 101–104.

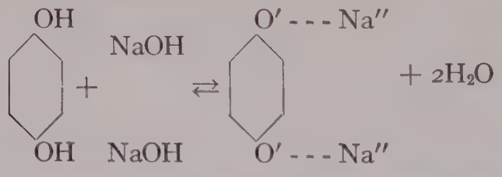
4. *The keeping properties required and the way in which the solution is used.* Developers which are used once in a tray and then discarded naturally do not need to keep so well as those designed for use in tanks over a long period of time. On the other hand, the conditions under which the developer is used may favor rapid oxidation of the solution. The amount of oxidation, for example, is relatively greater in tray development than in a tank because a larger proportion of the solution is exposed to air. In certain of the processing machines used in motion picture film processing and photo-finishing, film is exposed to the air for some time in transfer from one tank to another or in passing over loops above the surface of the solution. In such cases, an increased amount of the preservative is required to prevent rapid oxidation of the developer and oxidation fog.

5. *The alkalinity of the solution.* The more strongly alkaline the developer, the more rapid the rate of oxidation; for satisfactory keeping properties it is necessary, therefore, to use an increased amount of preservative. Under given conditions, a larger amount of preservative is required with the caustic alkalis than with alkaline carbonates.

Insufficient amounts of the preservative result in rapid oxidation of the developer causing (1) a loss in developing power, (2) the formation of colored oxidation products which stain the gelatin and (3) oxidation fog.

Large amounts of the preservative improve the keeping properties of the developer but increase the time of development and reduce the effective emulsion speed through the solvent action on silver bromide.

The Alkali.—The developing agents may be regarded as pseudo-acids dissociating only slightly in solution. The addition of an alkali increases the degree of dissociation and increases the number of developing ions available for the reduction of the silver halide, thus accelerating the rate of development. In the case of hydroquinone,



The alkalies commonly employed in organic developers are the alkaline carbonates (such as sodium and potassium carbonate), the caustic alkalis, and for special purposes, the basic phosphates such as sodium tribasic phosphate and the borates and meta-borates.

Sodium carbonate is available in three forms, crystals ($Na_2CO_3 \cdot 10H_2O$), the monohydrate ($Na_2CO_3 \cdot H_2O$) and the desiccated (Na_2CO_3). One part of desiccated carbonate is equivalent to approximately 2.5 parts of the crystal form, while practically 17 per cent more of the monohydrate is required than of the desiccated.

Potassium carbonate is more soluble than sodium carbonate which is an advantage in preparing concentrated developers. However, it is more costly and the dry chemical has the disadvantage of absorbing water readily. Experience has indicated that it may be substituted for the sodium salt on a basis of molecular weight, i.e., 30 parts of potassium carbonate for 23 parts of sodium carbonate.[21]

The caustic alkalis are used chiefly with developers of low energy, such as hydroquinone, where high density and contrast are required. Both sodium and potassium hydroxide must be protected from the air as they absorb moisture and carbon dioxide. Both should be dissolved in cold water for, as considerable heat is involved in mixing, the solution may boil and spatter on the hands, causing serious burns. Fifty-six parts of potassium hydroxide are chemically equivalent to forty parts of sodium hydroxide.

The caustic alkalis promote the swelling of gelatin to a greater degree than do the alkaline carbonates. The latter are preferable, therefore, on this account and also because of their greater convenience in handling.

Borax ($Na_2B_4O_7 \cdot 10H_2O$) is a weak alkali which is used in the so-called fine-grain developers where a solution of low alkalinity is desired. While it would seem possible to secure the same results with an equivalent quantity of sodium carbonate, in practice borax has proved more satisfactory.

The use of tribasic sodium or potassium phosphate as an alkali was recommended by A. and L. Lumiere and A. Seyewetz[22] in 1895 who

[21] Sheppard and Anderson, *Brit. J. Phot.*, **72** (1925), 232.

[22] *Bull. Soc. franç. Phot.*, 1895.

Luppo-Cramer—Sodium and Potassium Carbonates in the Developer. Phot. Rund., **64** (1927), 202–204.

Seyewetz and Szymson—Influence of the Nature and Proportion of the Alkali on the Reducing Power of Photographic Developers. Bull. Soc. Franc. Phot., **21** (1934), 236, 250.

Sheppard and Anderson—Equivalence of Sodium and Potassium Carbonates in Developers. Brit. J. Phot., **72** (1925), 232.

Wall—The Alkalis in Development. Amer. Phot., (1922) 481; Brit. J. Phot., **69** (1922), 634.

claimed that, as compared with the alkaline carbonates, the tribasic phosphates show less tendency to cause stain and softening of the gelatin. In recent years, it has found some favor in fine-grain developer formulas. The tribasic phosphates may be used with any developing agent except those in which its solubility is too low, as is the case with paraminophenol.

With phenolic developers, it is possible to replace the usual alkalis with a substance, such as acetone ($CH_3CO \cdot CH_3$), which will facilitate the dissociation of sodium sulfite into sodium bisulfite and caustic soda, thereby providing the alkali necessary for the formation of the phenolate which is the actual developing agent.

In the case of hydroquinone, the reaction is probably:

$$2CH_3 \cdot CO \cdot CH_3 + 2Na_2SO_3 + C_6H_4 \cdot OH \cdot OH = 2(CH_3 \cdot CO \cdot CH_3NaHSO_3) + C_6H_4 \cdot ONa \cdot ONa.$$ [23]

The principal advantages of acetone are its freedom of any tendency to cause fog or swelling of the gelatin and slightly less stain with staining developers such as pyro; it is now seldom used.

Formaldehyde is employed almost exclusively in conjunction with hydroquinone in the preparation of developers designed for producing maximum density and contrast on sensitive materials intended for photo-mechanical purposes. Chemically, its action is comparable to that of acetone.

Effect of an Alkaline Bromide in Development.—The presence of an alkaline bromide, such as potassium bromide, lowers the degree of ionization of silver bromide, and by reducing the concentration of silver cations restrains development. The effect of an alkaline bromide on development is shown in Fig. 138. It is evident that with increased times of development not only the slope of the straight-line portion of the $D \log E$ curve increases but that it shifts towards the left so that speed increases with the gamma.

The restraining effect of an alkaline bromide is more marked with developers of low energy, such as hydroquinone, than with the more energetic, such as metol. The depression in density resulting from an alkaline bromide is for any particular developing agent approximately proportional to the logarithm of the bromide content and is equivalent practically to reducing the effective speed of the emulsion. The effect, however, becomes less marked as the time of development is increased.

An alkaline bromide is added to developing solutions chiefly for the purpose of preventing fog. The restraining effect of bromide is greater on fog than on the latent photographic image; however, since modern negative materials almost invariably contain free bromide, and restraining substances are formed in the process of development, a restrainer is omitted in many developing formulas and the solution "conditioned" before use by developing waste film, or by adding a small quantity of used developer. The restraining products added in this manner are more effective in preventing fog than is potassium bromide.

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[23] Seyewetz, *Le Negatif en Photographie.*

A number of organic substances have been discovered which, for a given depression of density, are more effective in preventing fog than is potassium bromide. These, however, have not come into general use.[24]

The restraining effect of bromide on fog enables development to be carried to a higher contrast; hence, to obtain the highest possible contrast in any particular emulsion, a comparatively high concentration of bromide is an advantage. This is particularly the case with sensitive materials of the process type.

Effect of Use on Developing Solutions.—With use, a developing solution becomes slower in action as a result of (1) depletion of the developing agent, or agents, and (2) the restraining effect of by-products of the process of development in the form of sodium bromide, sodium iodide, and developer oxidation products. Some of the sulfite is used up in combining with the oxidation products of the developing agent, but in view of the relatively large quantity of sulfite present in most developers, the decrease is insignificant. Only a small part of the total quantity of alkali is used up in development.

The by-products of development which accumulate in a used developing solution retard development and increase the time of development necessary for a given density and contrast. If present in more than a limited amount, development is so greatly restrained as to reduce

[24] Trivelli, A. P. H., and Jensen, E. C., *J. Frank. Institute,* **210** (1930), 287; (1931), 155. Wulff, U.S.P. 1,696,830. Citrates, tartrates and boro-tartrates act similarly to potassium bromide. Lobel, *Bull. Soc. franç. Phot.,* 1928, 167.

Lobel and Lefevre—Action of Citric Acid on Metol-Quinol Developer. Bull. Soc. Franc. Phot., **14** (1927), 48–50.

Lobel—Tartrates and Boro-tartrates as Restrainers. S.&I.P. Inf. Cine., **8** (1928), 73.

Staud and Dundon—Photographic Developer Containing an Antifogging Agent. (Eastman Kodak Co.) U.S.P. 2,080,017 of 5.7.35.

the density of the highlights and shadows of the image even upon prolonged development, resulting practically in a loss in effective emulsion speed. A used developer, therefore, is incapable of getting the most out of an exposure, and a normally exposed image developed in a used solution appears to be underexposed.

In general, developing agents, such as metol, with a high reduction potential are less sensitive to the restraining effect of developer by-products than those of low potential such as hydroquinone and glycin.

The loss in density and contrast due to partial exhaustion of the developing solution may be overcome to a certain extent by the addition of a replenishing solution, which may be either a solution of the same composition as the original formula, but without bromide, or a more concentrated solution containing a larger proportion of the developing agent, or agents, and alkali. It is not possible, regardless of the composition of the replenishing solution, or the conditions of replenishment, to bring a partially exhausted developing solution back to its original condition. However, with suitable replenishment the period over which a developing solution may be used without involving an excessive loss in the density and contrast of the image may be greatly extended.

In motion-picture processing, where the technique of developer replenishment is most highly advanced, the developing solution is usually circulated through a large auxiliary storage tank and a certain proportion of the total volume is replaced constantly with fresh solution. In some cases, however, fresh developer is allowed to flow into the developing tank near the point at which the undeveloped film enters and the partially exhausted developer is drawn off from the point where the film leaves the developing tank. Experiments have shown that if development is begun in a fresh solution, the film may be transferred to a partially exhausted solution as soon as the shadow detail has appeared, without loss of effective exposure. In other words, once the detail in the shadows has appeared, a partially exhausted solution is capable of building up the density and contrast required for good negative quality.

Blaney—Method of Removal of Excess Halides from Photographic Developing Baths. U.S.P. 2,073,621 of 6.10.33.

Harvey, Woosley and Baines—Exhaustion and Regeneration of Developers. Proc. Ninth Int. Congress of Phot., Paris, 1935. S.&I.P. (II), **6** (1935), 300.

Weisberg (Greenwald)—Regeneration of Photographic Developer Solutions. U.S.P. 2,073,664 of 9.9.33.

In small-scale processing the usual method is to maintain the level of the solution in the tank through the addition, from time to time, of a replenishing solution which contains sufficient of the developing agent, or agents, and alkali to offset the restraining action of the developer reaction products. Only sufficient sulfite need be added to insure satisfactory keeping properties of the replenishing solution.

By adding sufficient replenishing solution to maintain the level of the developing solution in the tank, the replenishing solution added is equal in volume to that of the developer which has been removed from the tank on the sensitive material. This in turn is directly proportional to the amount of material processed; hence, the amount of replenishing solution added is directly proportional to the amount of sensitive material which has been developed.

The only satisfactory method of determining the best formula and the amount of replenishing solution required is by actual photographic tests made by developing sensitive material under known conditions.

Testing the Condition of a Developing Solution.—One of the most satisfactory methods of determining the condition of a developer is to secure a number of test negatives which have all received the same exposure and develop one of these for the average time in the fresh solution as a standard. Tests of the condition of the developing solution may be made from time to time by developing one of the negatives and comparing it with the standard. When it is evident that there is a loss in negative density and shadow detail, the solution should be replenished. The amount of replenisher necessary may be determined by developing another test negative for the standard time. The amount of the replenisher solution added should be sufficient to produce with this standard time of development a test negative which matches the standard.

The supply of test negatives required for testing the condition of the developing solution is conveniently made by contact printing from a master positive.

A variation of the above method consists in developing a standard exposure for a definite time, stopping development instantly with a stop bath containing acetic acid and potassium iodide and comparing the image so obtained with a previously prepared standard. The composition of the stop bath is as follows:[25]

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[25] Dundon, Capstaff and Brown, *J. of the Soc. of Mot. Pict. Eng.*, 14 (April, 1930), 389.

Potassium iodide	20 grams
Glacial acetic acid	20 cc.
Potassium alum	40 grams
Sodium sulfite	1 gram
Water to make	1 liter

The acetic acid instantly stops the action of the developer and the iodide converts the undeveloped silver bromide to silver iodide which is not darkened by light. The alum serves to harden the film and the sulfite prevents the solution from becoming colored because of the action of light on the potassium iodide. The bath can be used repeatedly as long as it remains acid.

The method of making the test is as follows: A strip of film or bromide paper containing a standard exposure, preferably a print from a step-tablet is quickly dipped into the developer and the time noted. While in the developing solution, it should be kept in motion to prevent non-uniform development. When testing a fresh solution the strip should be examined from time to time and removed from the developer when all except the last exposure step is visible. This time constitutes the standard. The strip should be removed immediately and placed in the stop bath. It may be examined in a bright light within 10 to 15 seconds after having been placed in the stop bath.

To determine the degree of exhaustion of a developing solution, a similar test strip should be developed for the standard time and, after immersion in the stop bath, compared with the strip developed in a fresh solution. The loss in density and shadow detail is easily seen.

The advantage of the dip test is that little time is required—three or four minutes being sufficient—and the differences are more readily seen than in a developed and fixed negative. With a little experience, a mere glance at the test strip is usually sufficient for an exact comparison.

Sensitometric Control of Processing.—In the processing of motion picture film sensitometric methods of developer testing and control are employed exclusively. The method employed is as follows: the time of development is first found by developing a number of sensitometric strips for different times, measuring the degree of development or gamma for each of the strips and determining from the time gamma curve the time of development necessary for the desired gamma. Then at half-hour intervals, other sensitometric strips are developed, the

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CRABTREE—Photographic Methods of Testing Developers. American Annual of Photography (1922), p. 184.

results plotted, and the value of gamma ascertained. If the gamma of the test or " control " strip is less than that accepted as the standard, more replenisher solution is added to the developer to bring the solution up to the desired condition.

Measurements to determine the consistency of density (in other words, to detect any loss in effective emulsion speed due to the partial exhaustion of the developing solution) are made by comparing the density for a given exposure on the sensitometric test strip to that on the sensitometric strip regarded as the standard. Obviously, if the developing solution is so controlled as to maintain a uniform gamma and density for given exposure, negative quality likewise should be uniform.

The time and labor involved in sensitometric control render such methods suitable only in large scale production.

CHAPTER XIV

NEGATIVE DEVELOPMENT

The Time of Development.—The time of development is determined by (1) the degree of development, or γ, desired and (2) by the time of development required under given conditions to reach that gamma.

The effect of increasing the degree of development, or γ, is to increase the density scale, or contrast, of the negative, hence, the degree of development depends upon the density scale desired in the negative. This in turn depends upon:

1. *The exposure scale of the paper.*

   The longer the exposure scale of the paper (lower contrast) on which the print is to be made, the greater the range of density required in the negative.
2. *The manner of printing.*

   Projection printing tends to increase the contrast of the print particularly if condensing lenses are used, so that, in general, negatives should have rather less contrast for projection printing than for contact printing.
3. *The brightness range, or contrast, of the subject.*

   As the brightness range of the subject increases, the degree of development, or γ, required to produce any given range of densities in the negative becomes less and less. Thus, assuming that the print is to be made on a particular printing paper, negatives of subjects having an extended brightness range such as landscapes including figures beneath trees and open sky, snow scenes with dark objects or shadows near the camera and many interiors, require a lower gamma than subjects of low contrast, as for example, open landscapes, ordinary landscape on dull day, water and sky, old and weatherbeaten buildings in dull light, athletic events in the open, etc.

The time of development required to reach any given gamma depends upon:

1. *The developer.*

   This involves (1) the formula and (2) its previous history; i.e. whether fresh or used and, in case of the latter, the degree of exhaustion.

2. *The conditions of development.*

   Included under this head, are such factors as degree of agitation and temperature.

3. *The developing speed of the film or plate.*

   Sensitive materials differ considerably in the time of development required to attain a given stage of contrast. Comparative values for most negative materials may be obtained from the Burroughs Welcome Diary and Exposure Guide, published annually.

Effect of Temperature on Development.—The effect of a given change in temperature on the time of development for a constant gamma is termed the *temperature coefficient.* The temperature coefficient, represents the difference in the time of development for a constant gamma at a temperature difference of either 10° C. or 18° F. The temperature coefficient depends chiefly upon the developing agent; but variations in the proportion of alkali to the developing agent, the nature of the alkali, and the amount of soluble bromide present in the developer have to be considered in determining the temperature coefficient for any particular developing formula.

The temperature coefficients of a few of the more common developing agents are as follows:

Pyro-soda without bromide	1.5
Pyro-soda with bromide	1.9
Rodinal, azol, certinal, etc.	1.9
Glycin	2.3
Rytol	2.2
Pyro-soda (Watkins thermo formula), no bromide	1.5
Pyro-soda (Watkins thermo formula), with bromide	1.9
Metol-hydrochinone (Watkins thermo formula)	1.9
Hydrochinon	1.4 –2.25
Ortol	2.06

The use of developing agents of low energy, such as hydroquinone, at low temperatures may result in incomplete development, producing the effect of underexposure.

With a developing solution containing two developing agents one of which is highly sensitive to temperature changes, in other words having a high temperature coefficient and one having a lower temperature coefficient—not only the time but the character of development changes with the temperature. Thus in an elon-hydroquinone developer, only the elon functions actively as a developer at low temperatures, since hydroquinone is active as a developer only at temperatures 60° F. and higher. Elon-hydroquinone developer, therefore, should not be used at a temperature below 55° F.

Developing at a high temperature has a number of practical disadvantages; (1) the tendency of the developing solution to fog is increased; (2) the developing solution oxidizes more rapidly, which increases the tendency to stain and results in more rapid exhaustion of the developer; and (3) the gelatin swells excessively, which leads to blistering, frilling and reticulation of the film.[1]

Calculating the Time of Development at Different Temperatures and the Temperature Coefficient.—The simplest method of calculating the temperature coefficient is that indicated by Watkins.[2] A film is exposed and divided in half (or two identical exposures made). One of these is developed at any convenient temperature and the time of appearance noted. The other is developed at a temperature several degrees higher or lower, whichever is more convenient, provided that the lowest temperature is not under 55° F. and the highest above 75° F. The time of appearance at this temperature is noted also.

The temperature coefficient may now be determined from the following equation:

$$\frac{(\log T_a - \log t_a) \times 10}{T^o - t^o} = \text{log of T.C. for temperature difference of } 10^\circ \text{ C. } (18^\circ \text{ F.})$$

In other words, the difference in the logarithms of the two times of appearance, multiplied by 10 and divided by the difference in degrees C. of the two temperatures, is equal to the logarithm of the temperature coefficient.

A very ingeneous method devised by Alfred Watkins is even simpler. The times of appearance having been found for two different temperatures, a slip of paper is laid on the log scale of Fig. 165 and

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[1] Technique of developing at high temperature. See page 325.

[2] Watkins Manual.

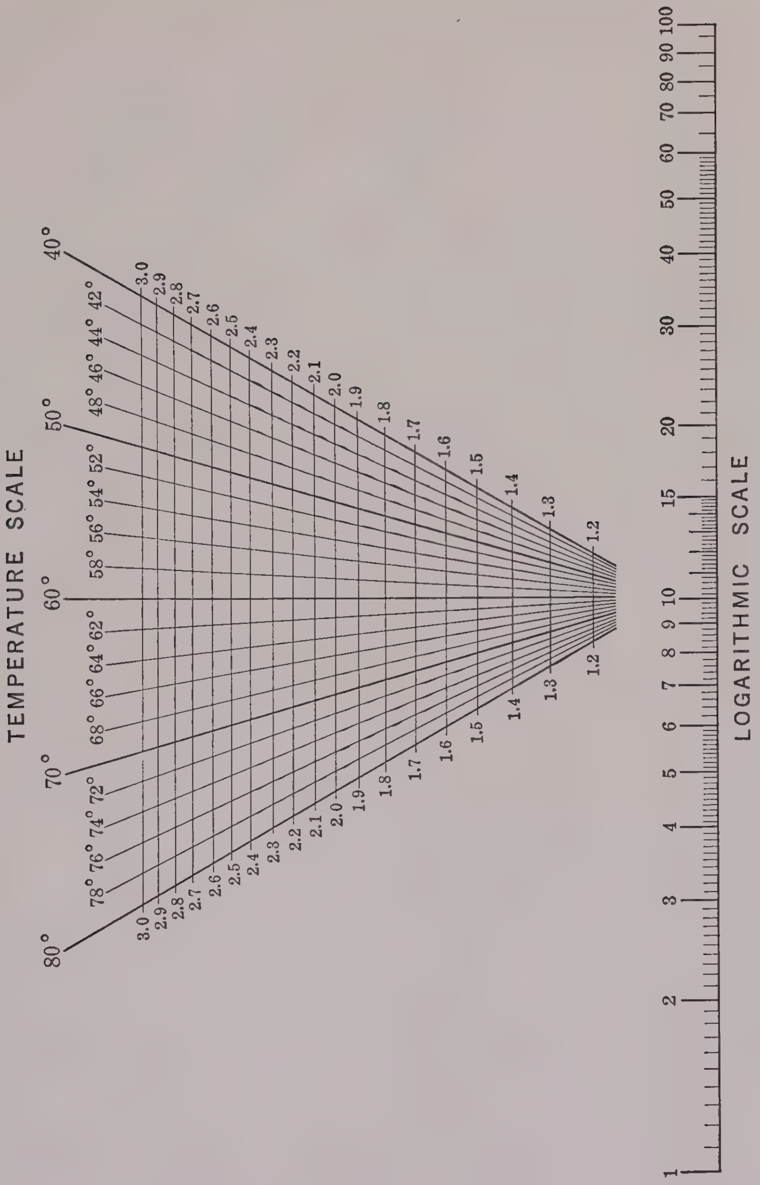

FIG. 165 Watkins Method of Calculating the T.C.

the times of appearance marked off against the corresponding values of the log scale. Beneath the marks are placed the respective temperatures. This slip of paper is then laid on the fan-shaped diagram and adjusted so that the two marks cut the lines of the two temperatures, the edge of the paper being along one of the horizontal lines. The point at which the paper intersects the radial temperature lines is marked with the temperature coefficient.

The time of development at various temperatures may now be found quite simply. Place the edge of a sheet of paper on the horizontal line corresponding to the temperature coefficient and mark off the points of intersection with the temperature lines. Transfer this scale to the log scale at the bottom of the diagram, placing opposite the time of development in minutes the corresponding temperature at which the test was made. The times of development at other temperatures may now be written down directly from the scale.

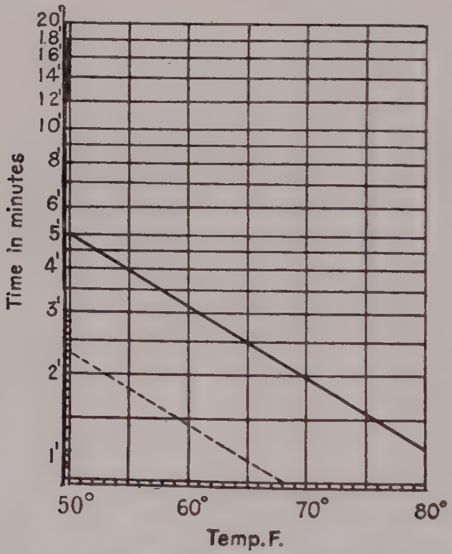

Fig. 166. Stokes Time Development Chart

If the time of development for a constant gamma at two tempera-

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Boucher—Control of Negative Contrast by Dilution of the Developer. Amer. Ann. Phot., 51 (1937), 23.

Nietz and Whitaker—Effects of Dilution and Stirring of a Photographic Developer. Brit. J. Phot., 73 (1926), 630–632, 645–647, 660–661, 676–677.

tures is known, a straight line drawn through these points when plotted on a log scale of time of development as the ordinates and an even scale of temperatures as the abscissae will indicate the time of development at intermediate points (Fig. 166).[3]

Effect of Dilution on Developers.—Slight dilution of the developer affects principally the time of development and its fogging tendencies; with greatly diluted developers the character of the image is modified and it is not possible to obtain the same result as with an appropriate time of development in a more concentrated solution.

Very dilute developers produce images of soft gradation and, generally speaking, it is not possible to obtain images of the same vigor and density as with concentrated solutions however much the time of development may be increased. With an extremely weak solution, development is confined more or less to the upper layers of the emulsion, due to the exhaustion of the developer in penetrating the emulsion and the restraining influence of the by-products of development.

Extremely dilute developers are capable, therefore, of developing more or less completely the shadow portions of the image, but are incapable of developing the highlight areas fully and thus lead to negatives of soft gradation. Certain practices of development employed for obtaining images of soft gradation from contrast subjects make practical applications of this principle. (See p. 331.)

The time of development for a given contrast (gamma) is not directly proportional to the dilution, except in the case of developing agents which are not directly oxidized by air. The only important example of a developing agent which is not oxidized directly is glycin, and with glycin developers the time is almost directly proportional to the concentration of the developer, except when considerably diluted. With organic developing agents other than glycin, the oxidation occurring within the solution results in the concentration of the developing agent being less than that indicated by the degree of dilution. Hence, the time of development, for the same negative contrast (gamma), is not directly proportional to the dilution, but is somewhat greater, depending upon the developing agent and the conditions of development.

While there appears to be no direct relationship between the concentration of the developer and its fogging tendencies, fog tends to increase both with highly concentrated or with extremely dilute developers. The increased fogging tendency of dilute developers is probably due to oxidation fog.

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[3] Stokes, *Brit. J. Phot.*, **68** (1921), 97.

Agitation.—In a stagnant developer, the by-products of the reaction remain close to the place of formation and restrain development. Agitation removes the restraining substances from the immediate vicinity of the film or plate and in so doing increases the rate of development. Hence, the time of development required to reach a given gamma with a particular developer and sensitive material varies with the degree of agitation. The time of development is less, for example, in a vigorously rocked tray than with the same developer in a tank because of the more efficient agitation of the developing solution. Likewise, the substitution of continuous agitation by mechanical means for intermittent agitation by hand (such as lifting the hangers carrying the film out of the solution and replacing) increases the rate of development and shortens the time necessary to attain a given gamma.

Insufficient agitation may also give rise to variations in density which are the direct result of inequalities in development. In the case of a film or plate developed in a vertical position and without sufficient agitation, the reaction products released from an area of high density on diffusing downwards along the surface may restrain development in the adjacent portions of the image producing streaks such as those shown in Fig. 167. This is more apt to occur when a high density is adjacent to and above an area of lower density. In the case of development in a horizontal position, lack of agitation, through the operation of the same principle may result in a silhouette effect. This phenomenon is known as the Mackie line after Alexander Mackie who explained the cause of such variations in density in the developed image.

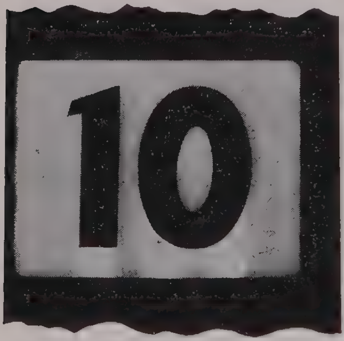

Fig. 167. Example of Directional Development. From Motion Picture Laboratory Manual. Eastman Kodak Co. 1936.

Crabtree—Directional Effects in Continuous Film Processing. J. Soc. Mot. Pict. Eng., **18** (1932), 207.

Crabtree—Uniformity of Photographic Development. J. Soc. Mot. Pict. Eng., **25** (1935), 512.

Smethurst—Developer Agitation in Plate Tanks. Brit. J. Phot., **84** (1937), 664.

Similar effects may be produced by agitation in one direction only. Such conditions apply particularly to the continuous processing machines employed in the processing of motion picture film where such defects are referred to as *directional development.*[4]

Methods of Determining the Time of Development.—The time of development required to obtain a negative having a suitable density scale may be determined by visual examination of the image from time to time during development. However, satisfactory results can be obtained by this method of developing only if one has acquired the ability (1) to recognize the density-scale required and (2) to make the proper allowances for (*a*) the dim light of the safelight lamp and (*b*) the effect of the undeveloped silver halide, which increases all the densities of the image but reduces the density differences, or contrast, and is the cause of the "fixing back" (i.e. loss of density upon fixation) which is so disconcerting to one developing by inspection for the first time. Development by inspection is thus a matter of judgment based upon experience. As such it is not an ability which can be expressed in terms which convey a definite meaning to another; it must be acquired through practice. One suggestion, however, can be made; the density relationships of the partially developed negative are more readily estimated if it is held with the body of undeveloped halide (i.e., the back of the film or plate) away from the safelight facing the observer.

As it is absolutely necessary to expose the plate or film to the direct rays of the safelight for at least a few seconds in order to follow the progress of development, it is obvious that there is real danger of fog with high speed materials unless desensitized. With supersensitive and hypersensitive panchromatic plates and films exposure to light of any kind during development is inadvisable and development by inspection is really practical only if a desensitizer is employed.

The numerical relation of the time of appearance of the image and the time of development for a given gamma, is sometimes called the *arithmetical coefficient of development,* or more frequently the Watkins factor, after Alfred Watkins who developed a method of determining the time of development based upon this relationship (factorial development).

For a constant gamma, the factor depends chiefly upon the developing agent and is not altered by temperature, by variations in the proportion or nature of the alkali employed, nor the dilution,—except in the case of pyro and diaminophenol. In general, the factor does not change for different emulsions except with some few which contain a large percentage of iodide.

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[4] *Motion Picture Laboratory Practice,* Eastman Kodak Co., 1936.

The factors for a few of the common developing agents are as follows:

Adurol	5	Certinal	30
Pyrocatechin	10	Amidol (2 gr. to the oz.)	18
Hydrochinon (min-KBr)	5	Rodinal	40
Hydrochinon (max-KBr)	4½	Ortol	10
Eikonogen	9	Edinol	20
Glycin (Carb. Soda)	8	Metol	30
Glycin (Carb. Potash)	12	Quinomet	30
Paramidophenol	16		

Pyro-soda

Without Potassium Bromide	Factor	With Potassium Bromide	Factor
1 gr. to the oz.	18	¼ gr. KBr per oz.	9
2 gr. to the oz.	12	½ gr. KBr per oz.	5
3 gr. to the oz.	10	¾ gr. KBr per oz.	4½
4 gr. to the oz.	8	1 gr. KBr per oz.	4

Pyro-acetone—about double the above.

With any given developing agent the factor depends upon the degree of contrast, or gamma, which it is desired to reach. Once the factor is found for any given set of conditions the time of development can always be readily determined by multiplying the time of appearance by the proper factor.

As a means of determining the time of development, the factorial method has two disadvantages: (1) the time of appearance, and consequently the time of development, varies with the exposure so that underexposures are overdeveloped and overexposures, underdeveloped; (2) the difficulty of applying the method to color sensitive materials due to the danger of fog if the safelight is sufficiently bright to enable the first appearance of the image to be observed accurately. With panchromatic and highly sensitive orthochromatic materials, factorial development is practical only if the film or plate is first desensitized.

The factorial method has been used less and less in recent years and is now almost obsolete.

Time Development.—Development by time was largely the outgrowth of the photochemical investigations of Hurter and Driffield.

Ferguson and Howard investigated the rate of development at different temperatures and Alfred Watkins did much to render the method popular by his carefully compiled tables of the time of development at various temperatures for different films and plates.

Development by time does not depend upon acquired skill in the estimation of the density-range of a negative, nor on observing the time of appearance of the image.

Since visual examination of the image is unnecessary at any stage, time development is the only really satisfactory method in the case of panchromatic materials of extreme sensitivity (unless desensitized), in machine processing and to a lesser degree in large-scale processing by any method.

Development for a fixed time based upon the time required for a given gamma, however, does not allow for variations in the developer, in the developing time of different batches of the same plates or film, the degree of agitation nor variations in the time of development, required with different subjects to produce negatives suitable for a particular paper.

Tables indicating the time of development for a given contrast on plates and films of their own manufacture in certain recommended formulas are published by most manufacturers of sensitive materials.[5] In some cases, developing times are given for different gammas but little or nothing has been published on the gamma to which the negative of a given type of subject should be developed to be suitable for a particular printing paper. This difficulty is largely overcome in practice by selecting a paper with an exposure scale which is suitable for the negative. If the negative must be developed so as to produce the desired result on a particular paper one can do more for himself through a few systematic, carefully planned and well conducted experiments than others can do for him.

Desensitizing Photographic Materials.—One of the most noteworthy additions to photographic technique during the last decade has been the discovery of efficient desensitizing substances which enable

[5] Also in the Burroughs-Wellcome *Handbook and Exposure Guide* (Burroughs-Wellcome Ltd., New York) and the *Thermo Development Chart* (American Photographic Publishing Co., Boston, Mass.).

MEES AND WRATTEN—Development by Time. Brit. J. Phot., 57 (1910), 376; Phot. J., 50 (1910), 403.

WATKINS—Testing the Developing Speed of Plates. Brit. J. Phot., 68 (1921), 383.

development to be conducted in a bright light. It is only necessary to bathe the film, or plate, in a solution of the desensitizing agent before development (in some cases the desensitizing agent may be added to the developing solution) to reduce the sensitivity to such an extent that even panchromatic materials may be exposed to a comparatively bright light without danger of fog.

The first practical desensitizer (phenosafranine) was discovered by Luppo-Cramer in 1920.[6] Since then research has disclosed a number of other and more efficient desensitizers but no adequate theory of the process has yet been evolved. Effective desensitizers are found chiefly among quinoid dyestuffs, particularly among the azines, cyanines, triphenylmethanes and oxydzines.[7] There is apparently a close connection between sensitizers and desensitizers as both are found in closely related dyes and moreover Mills and Smith found that the replacement of the CH linkage of the quinolin rings in the iso and pseudo-isocyanines by N converted sensitizers into desensitizers.[8]

Certain differences may be noted among known desensitizers:[9]

1. Desensitizing agents for one halide are not always desensitizers for another.
2. The ratio between the speed of a photographic material before and after desensitizing appears to increase with the average grain size of the emulsion, but varies with different desensitizers.

[6] For a review of earlier work on desensitizers, see Wall, *American Phot.* **15** (1921), 651.

[7] Stenger, *Zeit. Wiss. Phot.*, **23** (1924), 11.

[8] Mills and Smith, *J. C. S.* (London), **121** (1922), 2724, and **122** (1923), 2288.

[9] Bloch, *Phot. Jl.*, **73** (1933), 7.

AMOR—Desensitizers and Chemical Fog. Brit. J. Phot., **72** (1925), 183.
DURHAM—Basic Scarlet N. Brit. J. Phot., **78** (1931), 326.
HAMER—Desensitizing Properties of Chrysoidine and Some of its Derivatives. Phot. J., **70** (1930), 232–233.
HAMER—Desensitizing Properties of Basic Scarlet N. Phot. J., **70** (1930), 436–437.
HAMER, FISHER AND LEESON—Chemical Study of Desensitizers. IV. Desensitizing Properties of Anthraquinone Derivatives. Proc. VIIIth Int. Congress of Phot., Dresden, 1931, 357–362.
LUPPO-CRAMER—Desensitizing and the Latent Image. Brit. J. Phot., **77** (1930), 151–153.
WALL—Development in a Bright Light. Amer. Phot., **15** (1921), 651.
CRABTREE AND DUNDON—Effect of Desensitizers in Development. Brit. J. Phot., **73** (1926), 404–406, 418–421, 434–437.

3. The reduction in sensitiveness is not the same for all wave lengths, but is relatively greater for the longer wave lengths than for the shorter.
4. In some cases, the substance desensitizes in one spectral region and sensitizes, but only slightly, in another.
5. A number of substances which are active desensitizers are not practical because of their fogging action. The latent image is not weakened by desensitizing unless the film, or plate, is exposed to yellow, orange or red light after desensitizing and before development. Exposure to light at this stage results in the bleaching of the latent image and its partial destruction. It is important, therefore, that desensitized materials be handled in a safe light until development has begun.[10]

It should also be noted that most desensitizers will destroy the latent image if several hours are allowed to lapse between desensitizing and development.[11]

In general, a desensitizer may be used either as a preliminary bath, or as an addition to the developing solution. Usually, two to three minutes are required for desensitizing in a preliminary bath. This operation must, of course, be carried out in a darkroom with the usual safelights, or in the case of panchromatic materials preferably in total darkness. When the desensitizer is added to the developer, three to four minutes should elapse before the film is exposed to light.

The only practical desensitizer yet found among inorganic substances is mercuric cyanide.[12]

According to Mayer and Walter,[13] the actual desensitizer is the complex $K_2Hg(CN)_4$. Unlike most other desensitizers, it cannot be used as a preliminary bath, but must be added to the developing solution. It is slowly precipitated in many developing solutions and is not suitable for use with developers containing pyro. The usual concentration is 1 part to 3000 parts of the developer.

Phenosafranine used at a concentration of 1:2000 as a preliminary bath, or 1:5000 as an addition to the developer, is an effective desensitizer for blue-sensitive and orthochromatic materials, but the reduction in sensitivity is not sufficient for panchromatic materials of high color sensitivity.[14]

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[10] Luppo-Cramer, *Brit. J. Phot.*, **77** (1930), 151. Dundon and Crabtree, *Amer. Phot.*, **20** (1926), 378.

[11] Carroll, *J. Phys. Chem.*, **29** (1925), 693.

[12] B.P. 280,525 of 1926; *Brit. J. Phot.*, **75** (1928), 233.

[13] *Brit. J. Phot.*, **75** (1928), 692.

Phenosafranine stains the gelatin and the fingers deeply. The stain may be removed by bathing the negative in a 5 per cent solution of sodium hydrosulfite for a few minutes after washing. However, the stain, if uniform, does not affect the printing quality of the negative, as blue and violet light are transmitted.[15]

The time of development with hydroquinone is decreased by desensitizing and with metol-hydroquinone in proportion to the amount of hydroquinone. With pyrogallol and diaminophenol, on the other hand, the time of development is increased.[16]

A precipitate forms when phenosafranine is added to some developers, particularly hydroquinone and, to a lesser extent, with pyrogallol and pyrocatechin.[17]

Pinakryptol was the first of three desensitizers introduced by the I. G. Farbenindustrie as a result of the investigations of E. König, B. Homolka and Robert Schuloff. It is a more efficient desensitizer than phenosafranine and, although the solution is colored, the gelatin is not stained.

Pinakryptol green[18] is more effective than phenosafranine with panchromatic materials. It is non-staining but has a distinct fogging action if the time of immersion is prolonged, or if the concentration is too high when used as a preliminary bath.[19] The addition of the desensitizer to the developer, however, has a beneficial effect on aerial fog.[20]

Pinakryptol green, whether used as a preliminary bath or as an addition to the developer, affects the time of development and the Watkins factor. The effect varies with different developing agents and whether it retards or accelerates development depends on the particular point at which the comparison is made.[21]

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[14] Hubl, *Amer. Phot.,* **19** (1925), 642.

[15] Odencrants, *Das Atelier,* **31** (1923), 184.

[16] Luppo-Cramer, *Der Phot.,* **31** (1921), 65, 109.
Crowther, *Brit. J. Phot.,* **68** (1921), 231.

[17] Luppo-Cramer, *Der Phot.,* **31** (1921), 193.

[18] Pinakryptol green has been described as 1 : 3 diaminophenylphenazonium chloride. Garbacheva and Lenkoeff, *Phot. Chem. Ind.,* **1** (1936), 59. See also Homolka, *D. R. P.,* 396, 402.

[19] Amor, *Brit. J. Phot.,* **72** (1925), 183.

[20] Dundon and Crabtree, *Amer. Phot.,* **18** (1924), 742; *Brit. J. Phot.,* **71** (1924), 719.

Pinakryptol green, however, is precipitated in many developers, particularly those containing hydroquinone. It can be used without difficulty in metol-hydroquinone developers, if the concentration of hydroquinone is not too high. No difficulty is experienced with glycin, metol or with paraminophenol, whether used with an alkaline carbonate or in the form of rodinal (page 280). The formation of a precipitate is retarded by the oxidation products of the developer, so that less difficulty is experienced in this respect if the developer has been conditioned by the addition of used solution or by use. When precipitation is likely, the desensitizer should be added to the developer slowly, with constant stirring and in as dilute a solution as possible.

Pinakryptol yellow is a more efficient desensitizer than either pinakryptol or pinakryptol green. It must be used as a preliminary bath as it is destroyed by the sulfite in the developer. A 1:2000 solution should be used as a preliminary bath for 3–5 minutes, and 1:5000 pinakryptol green added to the developer.

Basic Scarlet N, a product of the Compagnie des Matieres Colorantes, is, according to Moreau, a mixture of chrysoidin and phenosafranine.[22] It is less efficient as a desensitizer than the pinakryptols, but has less tendency to produce fog, when used as a preliminary bath. As compared with phenosafranine, it has the advantage of being practically non-staining since the stain disappears in washing. The concentration as a preliminary bath is 1:5000.

Tray Development.—Tray development is used chiefly by those who have only a few films or plates to develop at a time. Under such conditions, it is more economical than tank development because of the smaller quantity of solution required. While as satisfactory results may be obtained by one method as the other, there is greater danger of scratching or otherwise damaging the negative in tray development.

Steel enamel, glass, hard rubber or composition trays are used for developing and fixing, the first-mentioned being the most popular in this country. The enamel, however, is easily chipped, exposing the metal and rendering the tray useless unless the exposed area is covered immediately with a suitable enamel. Glass is an excellent material for trays and other photographic equipment as it is resistant to all photographic solutions and is easily kept clean. The glass trays supplied for photographic use, however, are heavy and breakable and are gradually falling into disfavor. Hard rubber trays are expensive, are rather easily broken and it is difficult to see if they are clean. Trays of plastic materials are not popular because of their weight and because they are easily broken. Stainless steel forms an excellent material for trays and other processing equipment but has not been widely used because of its cost.

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[21] Dundon and Crabtree, Ibid. Luppo-Cramer, *Phot. Ind.*, 1921, 534. Hubl, *Amer. Phot.*, **19** (1925), 642. Crowther, *Brit. J. Phot.*, **68** (1921), 231.

[22] *Amer. Phot.*, **20** (1926), 159.

Except when developing a single cut film, or plate, the tray should be larger than the negative. A tray at least twice as large as the negative should be chosen for cut film while a tray accepting four or six plates, depending upon size, saves time and labor. When developing roll film, the tray should be sufficiently large to enable the roll of film to be handled conveniently.

It is not a difficult matter to develop from a half to a full dozen cut films in a tray if care and the proper technique are employed. Each film, held by the edges, is immersed with a sliding motion so as to cover it completely with the developer at one sweep. It is then turned over once or twice to break any air bubbles which form and placed in one end of the tray. A second film is then immersed in the same way, turned over once or twice and placed on top of the first. The same procedure is followed for the other films until all are in developer. The films are then transferred one by one from the opposite end of the tray, back again and so on until developed.

Small glass plates may be held in the hand using the thumb and forefinger on opposite edges and submerged in the developer. With larger sizes, the usual practice is to place the plates side by side in the tray and pour the developer from a graduate so as to completely cover the plates in one sweep. The tray is then rocked continuously first from side to side and then in the opposite direction to provide the agitation necessary to prevent uneven development. Care must be taken not to allow the plates to overlap one another and cause scratches or uneven development.

The usual method of developing roll film in trays is to detach the film from the paper backing in the darkroom and then pass it back and forth in a U shape, one end in each hand, through a tray of water until limp and then through the developer for the full time of development. It is then rinsed in a tray of water and transferred to the fixing bath in which it is handled in the same manner. The developer-laden film is necessarily exposed to air much of the time during development, hence the developer employed should be one which does not stain readily nor produce oxidation fog.

Tank Development.—Tank development has become almost universal on account of its greater convenience, economy of time and solution, and lastly, but most important of all, superior results from the standpoint of uniformity and freedom from fog, scratches, and other physical defects.

Tank development makes possible the development of roll film in daylight, thus completing the all-by-daylight cycle from the loading of the camera to the finished negative. The first and best known of the daylight film developing tanks is the Kodak Film Tank. In this, the film is placed in a closed box and wound up in an apron which protects it from light and yet permits full access of the developer through the openings in the binding as shown in Fig. 168. After the film has been wound up in the apron, the cover of the transfer box is removed and the apron with the film inside it transferred to a tank containing the developing solution. A tight cover is provided in order that the tank may be inverted at frequent intervals to prevent uneven development. When development is complete, the developer is poured out and the tank flushed with water. This leaves so little developer in the film

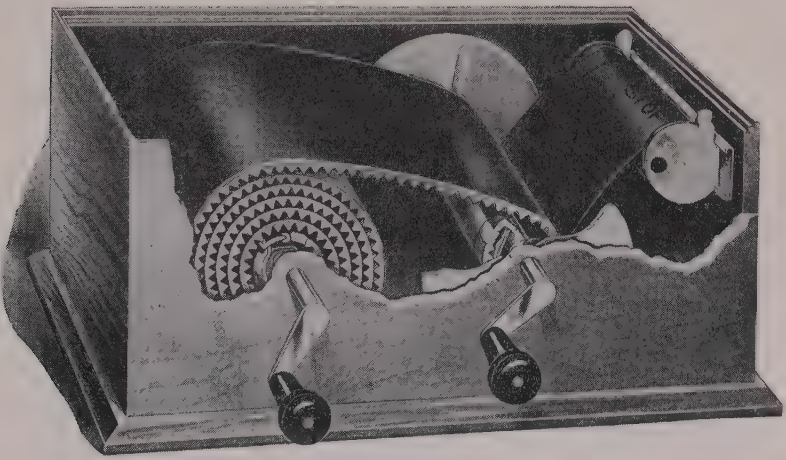

Fig. 168. Kodak Film Tank for Daylight Development of Roll Film

that it may be removed from the apron and transferred to the fixing bath in the light of an ordinary room.

Another tank for developing roll film in daylight is built in the form of a tube into which the developer is poured through an opening in the top. The roll of film is attached to a holder at the top of the tank and the free end of the backing paper is connected to a plunger. The cover is then placed on the tank and the plunger depressed to unroll the film in the developer.

A third type of tank for the development of roll film consists essentially of the tank proper and a spiral reel for holding the film during development. The film is separated from its paper backing and wound on the reel in the darkroom. The film is held in the spiral turns of the reel. The loaded reel is then placed in the tank containing the developer and the cover attached. In some cases, the cover is placed on the tank first and the developer added through a light-tight opening in the top. In this case, the tank may be emptied, the film is rinsed and the fixing solution added before exposing the film to light. While tanks of this type do not enable film to be developed in daylight, since a darkroom is necessary for loading, there is no apron and consequently no danger of markings on the back of non-curling films from contact with the apron during development. This is important in the case of small negatives because such markings sometimes appear in the enlargement. The reel, however, must be designed to permit the free circulation of the developer or it is difficult to avoid uneven development.

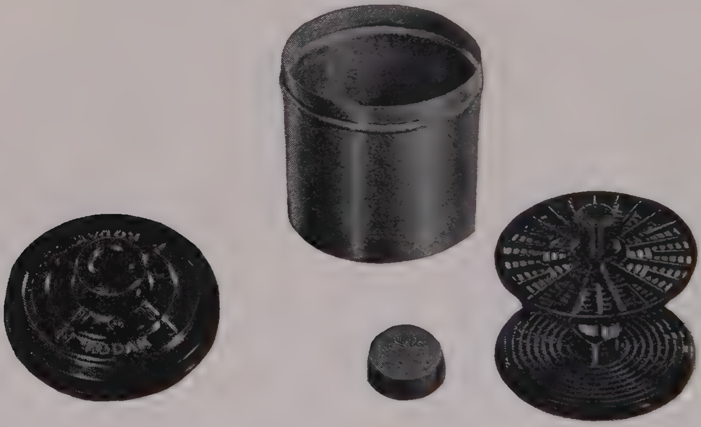

Fig. 169. Film Developing Tank (Kodak)

Tanks for the development of cut film and plates may be divided into two classes: closed and open.

Closed tanks are intended chiefly for amateur use and have a rack holding either 6 or 12 films or in a vertical position. Frequently, the same rack may be used for both plates and cut film, the film being first inserted in thin metal holders and these in turn inserted in the grooves of the developing rack (Fig. 170). In some cases, the rack is adjustable so as to accept plates or cut film of different sizes. The tank may or may not have a light tight opening in the side or top through which the developer and other processing solutions are added or the tank emptied.

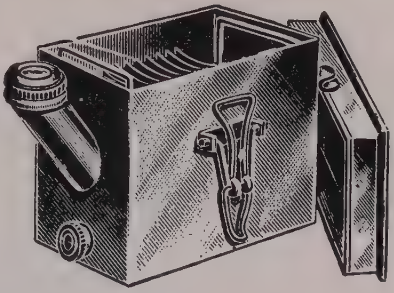

Fig. 170. Developing Tank (Closed Type) for Plates or Cut Film (in Septums).

A special form of tank designed primarily for film packs but suit-

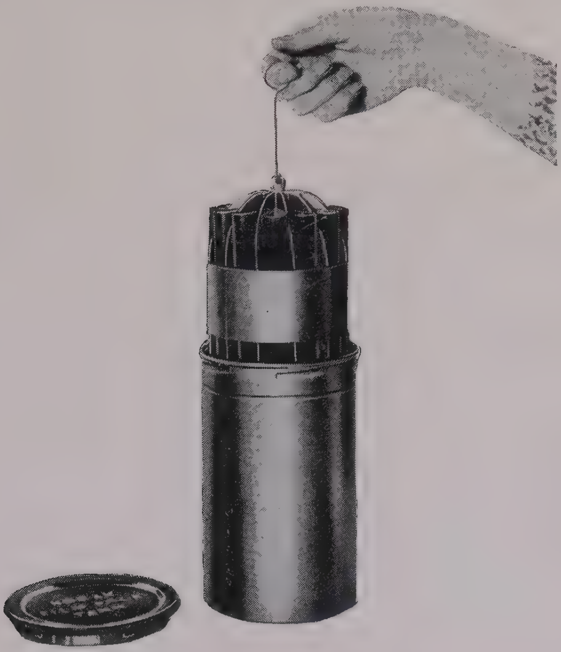

Fig. 171. Film Pack Tank (Kodak)

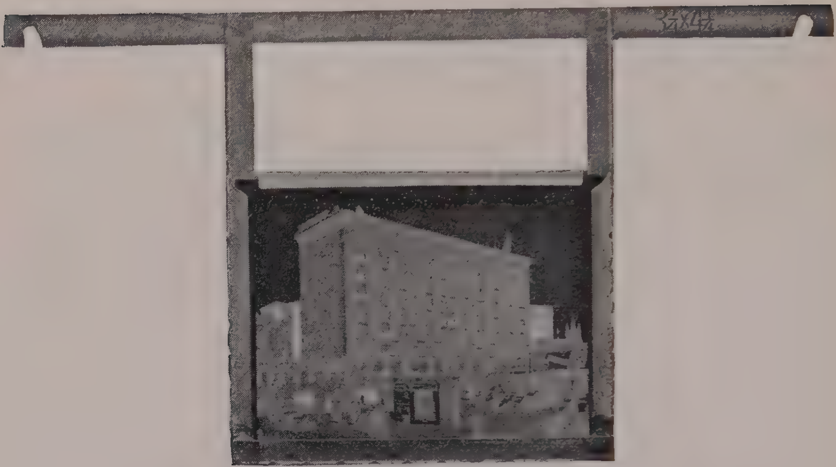

FIG. 172. Developing Hanger for Cut Film (Eastman)

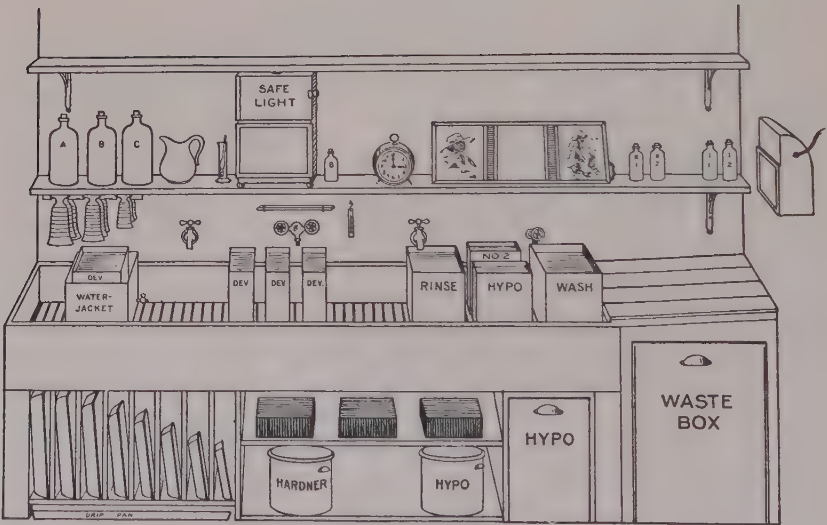

FIG. 173. Drawing of Well-Arranged Darkrooms for the Processing of Cut Film on Plates in Hangers by the Open Tank System. (Courtesy of Eastman Kodak Co.)

able also for cut film is shown in Fig. 171. The exposed films are bent double with the attached paper backing remaining and slid into the separate compartments of the cage. The loaded cage is then transferred to the tank for development. It is usually necessary with all closed tanks to reverse the entire tank at regular intervals to prevent the reaction products of the developer from forming currents which give rise to uneven development.

Open tanks are used chiefly by professional photographers. The cut films or plates are carried separately through the various tanks on metal hangers (Fig. 172). A typical installation (Fig. 173) consists of three to four steel enamel, hard rubber or soapstone tanks accommodating from one to two dozen cut films or plates and requiring from one to five gallons of solution. The tank on the left is for the developer, the rinsing tank is to the right with an inlet and an outlet to permit water from the mains to run through the tank, and the third tank contains the fixing bath. Where warm weather is encountered for much of the year, a fourth tank for a hardening stop bath is placed between the rinsing and fixing tanks. Usually the tanks are enclosed

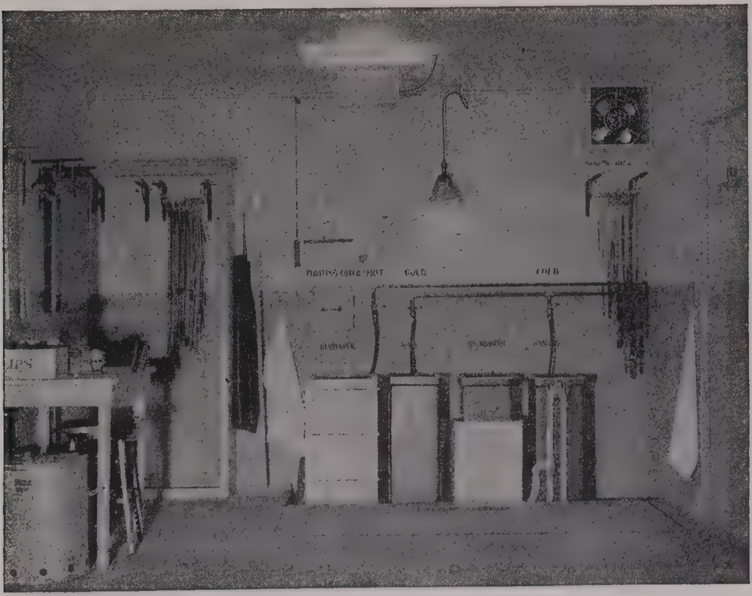

FIG. 174. Room and Deep Tank Installation for Commercial Processing of Roll Film. (Eastman Kodak Co.)

in a water jacket which is connected with the hot and cold water lines so that the temperature of the solutions may be kept uniform.

A typical deep tank installation for commercial photofinishing is shown in Fig. 174. The films are first separated from their backing papers, numbered, usually with a perforating numbering machine, and attached to a hanger from which they are suspended in the tank for development.

At the expiration of the required time of development, the hanger with its attached films is lifted from the tank and transferred to a rinsing tank through which water from the mains is kept flowing. In some cases, the films are transferred directly from the rinsing to the fixing tank; however, in locations where warm weather prevails for much of the year or films are dried rapidly by heat the rolls are usually first transferred to a tank containing a hardening stop bath of chrome alum and thence to the fixing bath. One or more tanks are employed for fixing and two or more for washing. The films are dried in cabinets with circulating heated air.

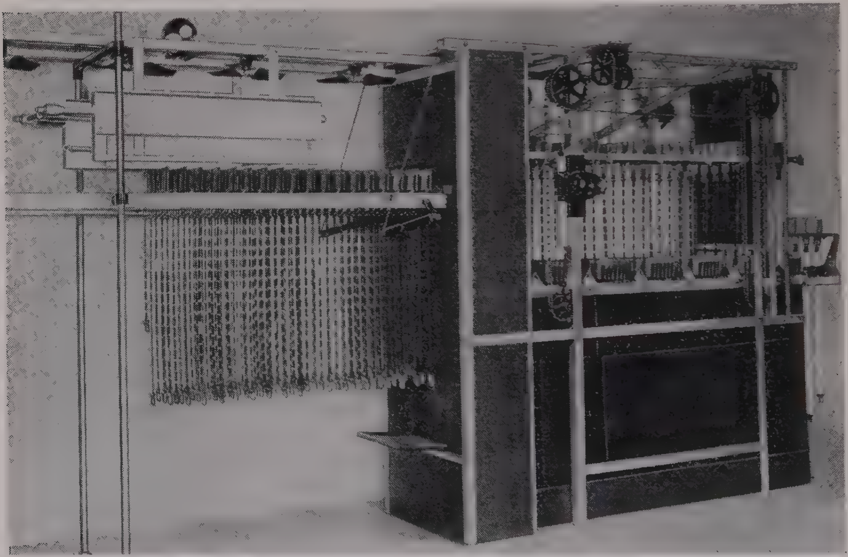

Fig. 175. Roll Film Processing Machine (Pako)

In recent years, automatic processing machines have been widely adopted for commercial photofinishing. These consist essentially of overhead conveyor systems which automatically transfer hangers containing the films from one tank to another. A typical processing machine for photofinishing is shown in Fig. 175 (Pako).

Factors Affecting Graininess.—The individual grains of silver halide in an emulsion are too small to be seen except with a high power microscope. In the coating and drying of the emulsion, however, the grains tend to draw together forming clusters of grains and development is accompanied by a clumping of the grains to form still larger masses of silver thus increasing the degree of inhomogeneity. It is the larger masses of silver formed as a result of the clumping of the individual grains which is the source of the inhomogeneity, or *graininess,* evident in photographic images at moderate magnification.

Among the factors affecting graininess are:

1. *The emulsion.* In general, finer grain is secured with slow materials than with fast; however, considerable progress has been made in this direction by the manufacturers of sensitive materials and some of the fine-grain films now compare favorably with all except the slowest positive materials.

2. *The density of the silver deposit.* Under given conditions, and with all emulsions, the graininess increases with the density up to a maximum which varies with the emulsion and the conditions of development. From this, it is evident that the various tones of the image exhibit varying degrees of graininess according to their density. Graininess is always more in evidence in the lighter tones of the positive and in an area of relatively uniform brightness such as the sky or the face. Factors which keep the density of the negative as low as is consistent with good negative quality; namely the avoidance of overexposure and development to a low gamma, are desirable in securing fine-grain images.

3. *The degree of development or* (γ). Since the development of a grain of exposed silver halide is progressive, starting from a center, or nucleus, on the silver halide grain and continuing until the entire grain is reduced to silver, it is evident that if development is arrested at an early stage, the grains will be only partially developed and the particles of developed silver comprising the image will be smaller, and the clumping less, than if development is carried nearer to completion. Since the visibility of the grain and grain clusters,

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THREADGOLD—Measurement of Graininess (of Photographic Emulsions). Phot. J., **72** (1932), 348.

VAN KREVELD—Graininess and Resolving Power of Photographic Emulsions. Phot. J., **74** (1934), 590.

which determines the graininess of the image, is proportional to their size, it is apparent that a developed image of any given density obtained in one case by full exposure and a low degree of development will, in general, exhibit less graininess than one which has received less exposure and has been developed to a higher gamma.

4. *The composition of the developer and conditions of development.* Much has been published in recent years regarding fine-grain developers and development. A great deal of this information is based upon theories and data of questionable validity and many of the claims cannot be substantiated in practice. Quantitative data is lacking on many processes and methods which have been highly publicised and the entire subject is one in which quantitative investigation is sadly needed.

Metol-Hydroquinone-Borax Developers.—The first fine-grain developer of this type was published by Wellington,[23] but the first to achieve widespread popularity was that of Capstaff,[24] familiarly known as D–76.

	Avoirdupois	Metric
Elon	116 grains	8.0 grams
Sodium sulfite, desiccated	13¼ ounces	400.0 grams
Hydroquinone	290 grains	20.0 grams
*Borax	116 grains	8.0 grams
Water to make	1 gallon	4.0 liters

* The variety such as 20-Mule Team Borax.

Use without dilution. Average development time is 10 to 20 minutes at 65° F. (18° C.)

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[23] Wellington, *Manual.*

[24] Capstaff and Seymour, *Trans. Soc. Mot. Pict. Eng.,* **10** (1926), 223.

Bloch—Fine Grain Developers. Brit. J. Phot., **83** (1936), 368.

Bloch—Experiments with Fine-Grain Developers: Determining Relative Graininess. Miniature Camera World, **1** (1937), 343.

Crabtree—Graininess of Motion Picture Film. Trans. Soc. Mot. Pict. Eng., **11** (1927), 77–92.

Liesegang—Fine Grain Development. Phot. Ind., **32** (1934), 670. S.&I.P. (II), **5** (1934), 250.

Marriage—Effect of Processing Conditions on Graininess. Phot. J., **77** (1937), 379.

Selman—Kodak Ultra Fine-Grain Developer. Brit. J. Phot., **84** (1937), 467.

Seyewetz—Fine-Grain Images from Coarse-Grain Emulsions. Brit. J. Phot., **80** (1933), 511.

Directions for Mixing: Dissolve the Elon separately in a small volume of water (at about 125° F.) (52° C.). Then dissolve approximately one-quarter of the sulfite separately in hot water (at about 160° F. (71° C.), add the hydroquinone with stirring until completely dissolved. Then add this solution to the Elon solution. Now dissolve the remainder of the sulfite in hot water (about 160° F.) (71° C.). Add the borax and, when dissolved, add to the above solution. Dilute to volume with cold water.

Similar formulas but with the hydroquinone omitted are favored by many. A typical formula is:

Metol	1 gram
Sodium sulfite (des.)	150 grams
Water to	1000 cc.

Time of development: From 20 to 30 minutes at 65° F. (18° C.).[25]

Metol-hydroquinone-borax developers such as D–76 increase in alkalinity on standing, thus becoming more active, necessitating shorter developing times and producing coarser-grained deposits. A modified formula in which boric acid is used as a buffer does not increase in alkalinity and tends to produce finer-grain because the longer period of development necessitated by the addition of boric acid favors increased solvent action of the sodium sulfite.

	Avoirdupois	Metric
Elon	17.6 gr.	2.0 gm.
Sodium sulfite (dess.)	2.0 ozs.	100.0 gm.
Hydroquinone	43.8 gr.	5.0 gm.
Borax, granular	70.0 gr.	8.0 gm.
Boric acid, crystals	70.0 gr.	8.0 gm.
Water to	20.0 ozs.	1000.0 ccs.

Developing time from 20 to 30 minutes at 65° F. (18° C.).

The reduction in graininess obtained through the use of developers of this type is due to the solvent action of sodium sulfite on silver halide. This solvent action, which is at its greatest with silver chloride and relatively insignificant in the case of silver iodide, prevents the individual grains from attaining their full size in development and reduces the tendency of the grains in close proximity to one another from merging to form the larger aggregates of silver which are the chief cause of granularity in photographic deposits. The borax acts merely as a weak alkali indirectly favoring the solvent action of the sulfite.[26]

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[25] Dupont Fine-Grain Formula.

The use of diaminophenol and ammonium chloride as a solvent of silver halide was suggested by Lazenby.[27]

Increasing the amount of sodium sulfite, or reducing that of the developing agents, results in increased solvent action and favors the production of images of finer grain as does the addition of potassium bromide, but at the expense of effective emulsion speed, necessitating increased exposure and longer times of development. The following table shows the effect of the addition of potassium bromide to the D–76 Elon-hydroquinone developer on effective emulsion speed and time of development.

Grains of Potassium Bromide per gallon	Effective Emulsion Speed	Relative Time of Development
0.0	100%	1.0
150.0	50%	1.6
300.0	25%	2.2

Paraphenylene Developers.—The suitability of paraphenyldiamine where a fine-grain image is required was noted by A. & L. Lumiere and A. Seyewetz in 1904. It is probable that development with paraphenylene[28] due its solvent effect on the silver halide is partly physical in character (page 329) and its low reduction potential favors the solvent action of both the developing agent and the sodium sulfite.

Used alone, paraphenylene has several disadvantages: (1) the rate of development is low so that comparatively long times of development are required, (2) the loss in emulsion speed is considerable, necessitating from three to four times the exposure required for normal developers, (3) the density and contrast of the image are low, and (4) the solution is toxic, producing painful skin eruptions in some people.

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[26] A developer similar to the D-76 formula of Capstaff but using sodium carbonate with sodium phosphate as a buffer has been described by Seyewetz. *Bull. Soc. franç. Phot.*, **22** (1935), 236.

[27] *Brit. J. Phot.*, **81** (1934), 663.

[28] *Bull. Soc. franç. Phot.*, **20** (1904), 422.

Seyewetz—Production of Fine-Grain Images by Development Followed by Intensification. Bull. Soc. franc. Phot., **24** (1937), 45.

Vittum and Crabtree—New Fine-Grain Developer. Brit. J. Phot., **84** (1937), 385.

Willcock—Metol-Glycin for Fine-Grain Development. Brit. J. Phot., **83** (1936), 576.

Willcock—Buffered Developers. Brit. J. Phot., **84** (1937), 641.

These disadvantages, except the last, are partially overcome by combining paraphenylene with glycin or metol.

For a paraphenylene developer, the following is recommended:

Paraphenylenediamine	145 gr.	10 gm.
Sodium sulfite (des.)	1 oz. 290 gr.	50 gm.
Water to	32 oz.	1000 cc.

The paraphenylene is dissolved first in water at about 160° F., and when thoroughly dissolved, the sulfite is added. As the keeping properties of the mixed solutions are poor, no more should be prepared than will be used in a single day.

The time of development is from 30 to 50 minutes at 65° F. (18° C.) depending upon the sensitive material and the degree of contrast desired. The maximum gamma obtainable with modern super-sensitive and hypersensitive materials varies from .5 to .8.

Paraphenylenediamine hydrochloride is proferred by many over the free base.

Paraphenylenediamine hydrochloride	90 gr.	6 gm.
Sodium sulfite (des.)	750 gr.	50 gm.
Trisodium phosphate	180 gr.	12 gm.
Water to	32 oz.	1000 cc.

The time of development ranges from 25 to 50 minutes at 65° F. depending upon the sensitive material and degree of contrast required.

The addition of glycin or metol results in a developer of greater energy producing greater contrast and density and with less loss in emulsion speed. Many compromise formulas of this type have been published; one of the best known is:[29]

Sodium sulfite (des.)	3 oz.	90 gm.
Paraphenylenediamine	150 gr.	10 gm.
Glycin	90 gr.	6 gm.
Water to	32 oz.	1000 cc.

In preparing this developer, the paraphenylene is dissolved first in water at about 160° F. (71° C.), then the sulfite and finally the glycin.

The time of development is from 20 to 40 minutes at 65° F., depending upon the sensitive material and degree of contrast required. The exposure must be approximately twice normal.

[29] Sease, *Camera* (Phila.), 47 (1933), 1.

Fleming—Paraphenylenediamine Developers from the Laboratory Viewpoint. Amer. Phot., 29 (1935), 614.

A similar developer, but with phenylenediamine-hydrochloride, is as follows:[30]

Sodium sulfite (des.)	3 oz.	90 gm.
Paraphenylenediamine hydrochloride	255 gr.	17 gm.
Glycin	90 gr.	6 gm.
Trisodium phosphate	510 gr.	34 gm.
Water to	32 oz.	1000 cc.

All developers tend to produce finer grain when partly exhausted, or if conditioned before use by one of three methods: (1) by developing scrap film which has been slightly exposed to light, (2) by adding exhausted developer to about 20 per cent of the total volume. *Old developer which has been used but not exhausted may be added to freshly mixed developer but should not be substituted for water in making up a fresh solution,* (3) by adding one-half gram (7½ grains) of sodium chloride to each liter of the developer and then, after it has dissolved, adding one-half gram silver nitrate which has been dissolved in a little water. It is best to dissolve all the ingredients except the silver nitrate in about 80 per cent or 90 per cent of the water called for in the formula. The silver nitrate is then dissolved in the remaining water and added to the main solution. A precipitate forms which is allowed to settle over night and the clear solution poured or siphoned off for use, and the exposure must be increased from two to three times that required with a normal metol-hydroquinone developer.

A number of workers have recommended the "preaging" of paraphenylenediamine before use.

In this process, the paraphenylene and sulfite are mixed dry and allowed to stand in a small tightly closed bottle which does not contain much air over the solid mixture, and left to stand at room temperature (not above 80° F.) for ten days. After ten days, the pre-aging is largely complete. The resulting mixture must be dissolved in hot water (150° to boiling) and the solution is wine-red or brown. Negatives developed in a pre-aged developer have many of the characteristics of physically developed negatives and if the correct exposure has been used, enlargements of considerable size are possible.

If the chemicals are mixed for pre-aging in a container which is wet, spoilage will result. On the other hand, if the chemicals are

[30] Lowe, *Zeiss Magazine,* II (1936), 75.

Lowe—New Fine-Grain Developer for Superior Gradation. Camera Craft, **43** (1936), 558.

mixed in exceedingly dry weather, the pre-aging will be very slow and it may be necessary to put one drop of water on the inner surface of the container lid (not on the chemicals themselves). This water will evaporate into the air around the chemicals and permit aging to go on at a reasonable speed.[31]

Two-Bath Development.—Methods of developing involving the use of two separate baths may be divided into three main classes:

Class 1: *Those in which the first bath contains all of the developing agents plus sodium sulfite and the second the alkali and the remainder of the sulfite.*[32]

The gelatin swells and absorbs a certain amount of the developing solution in the first bath but little or no development takes place owing to the absence of the alkali. When the film is transferred to the second bath development proceeds until the developing agents held in the gelatin have been exhausted or have diffused out into the surrounding solution. Developers of this type result in an almost constant degree of development (γ) regardless of the time of development or the temperature of the solution and hence possess certain advantages where a certain fixed degree of development (γ) is desired.

Two-bath developers of this type have a long useful life. The first bath is changed but little and requires only the addition of fresh solution to replace that carried out by the film. Reaction products which restrain development accumulate in the second bath which must be renewed frequently. The degree of development (γ) remains practically constant during exhaustion.

The following formula results in a gamma of from 0.5 to 0.6 depending upon the characteristics of the sensitive material:

[31] Reducing grain by redevelopment in paraphenylenediamine, hydrochloride. Heymer, *Veröffentl. Wiss. Zentral Lab. Agfa,* **4** (1935), 198.

[32] von Joanovich, *Phot. Korr.,* **44** (1907), 359, 505. Knapp, *Brit. J. Almanac,* 1932, 191. Crabtree, Parker and Russell, *J. Soc. Mot. Pict. Eng.,* **21** (1933), 21. Baker, *Brit. J. Phot.,* **56** (1909), 609; **58** (1911), 101.

FORMSTECHER—Development in Two Successive Baths. Phot. Ind., 29 (1931), 683, S.&I.P. (II), 2 (1931), 335.

Formula SD-4

	Avoirdupois	Metric
Solution *A*—First Bath		
Elon	5 lbs.	5.0 grams
Hydroquinone	2 lbs.	2.0 grams
Sodium sulfite, des. (E. K. Co.)	100 lbs.	100.0 grams
Sugar	100 lbs.	100.0 grams
Sodium bisulfite (E. K. Co.)	5 lbs.	5.0 grams
Water to make	120 gals.	1.0 liter
Solution *B*—Second Bath		
Sodium carbonate, des. (E. K. Co.)	10 lbs.	10.0 grams
Sodium sulfite, des. (E. K. Co.)	100 lbs.	100.0 grams
Potassium bromide	½ lb.	0.5 gram
Potassium iodide	70 grains	0.01 gram
Water to make	120 gals.	1.0 liter

The purpose of the sugar and bisulfite in the first bath is to restrain development and prevent the appearance of the image, thus extending the life of the bath by preventing the accumulation of restraining by-products resulting from development.

The degree of development (γ) may be varied within certain limits by modifying the composition of the two solutions. The following suggest some of the modifications possible and the approximate value of gamma with negative materials:[83]

Gamma	First Bath	Second Bath	Time of First Bath	Treatment Second Bath
0.5	*A*	*B*	4 min.	4 min.
0.7	*A* with 5 grams per liter of hydroquinone.	*B*	4 min.	4 min.
0.7	*A*	*B* with 50 grams per liter of sodium carbonate and double quantities of bromide and iodide.	4 min.	4 min.
0.9	*A* with 5 grams per liter of hydroquinone.	*B* with 50 grams per liter of sodium carbonate and double quantities of bromide and iodide.	4 min.	4 min.

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[83] Crabtree, Parker and Russell, J. Soc. Mot. Pict. Eng., 21 (1933) 21.

Class II: *Two-bath developers in which both contain the developing agents, sulfite and alkali but in different proportions.*

In developers of this type the first bath is designed to serve as a replenishing solution for the second. Since the quantity of the first bath carried over into the second is proportional to the quantity of film processed and if the formula of the first bath is designed to fit the particular conditions of use, the rate of development will remain uniform. Two-bath developers of this type, therefore, permit of greater exhaustion than do single bath developers without a corresponding loss in effective emulsion speed or rate of development.

Class III: *Two-Bath Developers of Like Composition.*

A two-bath developer of this type has a longer useful life than a single bath developer since development is begun in a fresh bath and completed in one which is partially exhausted. Investigation has shown that this may be done without loss in effective emulsion speed and without materially affecting the quality of the negative.[34]

The time of immersion in the first bath is short—only long enough for the image to appear—hence, the rate of exhaustion is much less than that of a single bath developer of the same composition. Then, when the second bath is exhausted, the first bath is replaced with fresh solution and it in turn becomes the second bath.

Processing at High Temperatures.—The primary problem in the processing of negative material at a high temperature is to avoid undue swelling of the gelatin with its attendant difficulties, frilling, reticulation, melting, separation from the base, etc. A secondary but important consideration is developing without producing an undesirable amount of fog or stain. The various methods of processing at high temperature may be divided into three classes.

1. Hardening before processing.
2. Hardening in development.
3. Prevention of swelling in development followed by hardening in a separate bath after development and before fixation.

Processes Based Upon Hardening Before Development. The most satisfactory substance for hardening prior to development is formalin (40 per cent formaldehyde) in alkaline solution or in conjunction with a salt—such as sodium sulphate, citrate or disodium orthophosphate—which has the property of repressing the swelling of gelatin in warm water.[35]

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[34] Dundon, Brown and Capstaff, *J. Soc. Mot. Pict. Eng.*, **14** (1930), 389.

Formalin hardens gelatin in alkaline solutions only and an undeveloped emulsion will soften if placed in a plain solution of formalin.

Methods Based Upon Hardening in Development. Under ordinary conditions, pyro and pyrocatechin are the only developing agents having a pronounced tanning action on gelatin. Metol-hydrochinon developers with a smaller than usual amount of sodium sulfite harden gelatin in consequence of the production of insolubilizing oxidation products.[36]

The tanning action produced in such cases is not uniform but varies with the density of the developed image and the developing solutions have poor keeping properties.

The addition of formalin to many developers results in strong fog and stains. Fogging may be reduced by the addition of a desensitizing agent such as phenosafranine or pinakryptol and by increasing the amount of soluble bromide. A two-bath developer, one bath containing the developers, the other the alkali and hardener is particularly advantageous for developing at high temperatures because under such conditions it is possible to use formalin without the troublesome reactions that occur between formalin and the developing agents in a single bath developer.[37]

The following two-bath developer is recommended at temperatures below 85° F. (29.5° C.).

First Bath

	Avoirdupois		Metric
Elon	44	grains	3 gm.
Sodium sulfite, desiccated	365	gr.	25 gm.
Hydroquinone	88	gr.	6 gm.
Sodium sulfate, desiccated	3¼	oz.	100 gm.
Sodium carbonate, desiccated	292	gr.	20 gm.
Water to	32	oz.	1 liter

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[35] The use of formalin and such salts for hardening is protected by British Patent 128,337 (*Brit. J. Phot.,* **66** (1919), 460).

[36] Lumiere and Seyewetz, *Brit. J. Phot.,* **75** (1927), 134.

[37] Parker and Crabtree, *Amer. Phot.,* 1936, 67, 142.

Second Bath

	Avoirdupois	Metric
Solution 2*A*		
Phenosafranine (1 : 1000 sol.)	5 dr.	20 cc.
Sodium sulfite, desiccated	1⅔ oz.	50 gm.
Potassium bromide	30 gr.	2 gm.
Water to	32 oz.	1 liter
Solution 2*B*		
Formalin (40 per cent sol.)	6 oz.	200 cc.
Water to	32 oz.	1 liter

Sodium sulfate is used in the first bath to prevent excessive swelling of the gelatin before it can be hardened by the formalin in the second bath. The purpose of the phenosafranine is to prevent the formation of the aerial fog which might occur from exposure of the film to air during development. A portion of the formalin in the second bath reacts with the sulfite, liberating sodium hydroxide, so that no additional alkali is required in the second bath.

The two parts of the second bath deteriorate slowly when mixed and the second bath, therefore, should be prepared immediately before use.

The film should be bathed for one minute in the first bath and then transferred, without rinsing, to the second bath and kept in constant agitation for one minute, care being taken not to expose the film to the air or aerial fog is likely to be produced. After development rinse briefly preferably in an acetic acid stop bath (1½ oz. 28 per cent acetic acid to 32 oz. water) and fix in an acid fixing and hardening bath.

If the desired contrast is not obtained, the time of immersion in the first bath may be increased slightly or the film may be rinsed briefly in water and reimmersed in the first bath for a short time.

Processes Based Upon the Prevention of Swelling During Development Followed by Permanent Hardening. The swelling of the gelatin during development may be reduced (*a*) by using concentrated developers and (*b*) by increasing the concentration of the developing solution through the addition of inert material such as sodium or potassium sulfate, glucose or sugar. The use of a concentrated developer, to reduce the time of development, and the addition of sodium sulfate, to prevent abnormal swelling of the gelatin, enables development to be conducted satisfactorily at temperatures of 75° F. (24° C.) to 90° F.

Jaenicke—Shortening the Development Time of Photographic Negatives. Phot. Ind. **35** (1937), 514, 540.

Lumiere and Seyewetz—Developers for Hot Climates. Phot. Rund., **63** (1926), 491.

(32° C.) if the film is permanently hardened in a chrome-alum-sodium sulfate stop bath immediately after developing and before fixing.[38]

The following developer is recommended:[39]

(Kodak Developer DK-15)

	Avoirdupois		Metric
Water (about 125° F.) (52° C.)	24	ounces	750.0 cc.
Elon	82	grains	5.7 grams
Sodium sulfite, desiccated (E. K. Co.)	3	ounces	90.0 grams
Kodalk	¾	ounce	22.5 grams
Potassium bromide	27	grains	1.9 grams
*Sodium sulfate, desiccated	1½	ounces	45.0 grams
Cold water to make	32	ounces	1.0 liter

Times for Tray Development
For roll film, cut film, and plates

Temperature	Time
65° F. (18° C.)	8 minutes
70° F. (21° C.)	6½ minutes
75° F. (24° C.)	5 minutes

This formula has the following advantages: (1) It is non-blistering because no gas is formed when the developer is added to the acid hardening bath or the acid fixing bath, (2) the development rate changes slowly with time so that on slight overdevelopment the negatives will not be too dense, (3) it minimizes greatly any tendency for aerial fog, and (4) it has a minimum scumming tendency in conjunction with the average acid fixing bath.[40]

After development, rinse the films or plates in water for *one or two seconds only* if the temperature is below 85° F. (29.5° C.) or, if the temperature is higher, omit the rinse entirely and transfer the films directly to the following tropical hardening bath:

	Avoirdupois	Metric
Water	32 ounces	1.0 liter
Potassium chrome alum	1 ounce	30.0 grams
*Sodium sulfate, desiccated	2 ounces	60.0 grams

* If it is desired to use Sodium Sulfate, crystals instead of desiccated, then 3½ ounces per quart (105 grams per liter) should be used.

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[38] The use of sodium sulfate and similar substances as an addition to developers for the purpose of preventing the swelling of the gelatin was recommended by Bunel, *Bull. Soc. franç. Phot.*, 1910, 174; *Brit. J. Phot.*, **57** (1910), 399, by Lumiere and Seyewetz; *Brit. J. Phot.*, **58** (1911), 137, and Eastman Kodak Co.; *Brit. J. Phot.*, **71** (1924), 762.

[39] *Tropical Development*, Eastman Kodak Co., 1936.

[40] Formula D-76 (p. 318) may be used with the addition of 1½ ounces of

Agitate the film for 30 to 45 seconds when first immersing it in the hardener, or streakiness will result. The bath is a violet-blue color by tungsten light (white bulb) when freshly mixed, but it ultimately turns a yellow-green with use; it then ceases to harden and should be replaced with a fresh bath. Allow from three to four minutes for hardening and then transfer to the usual fixing and hardening bath.

The Relative Temperature of the Various Solutions.—Regardless of the method employed in processing photographic materials at a high temperature, it is important that the temperature of the various solutions be kept as nearly alike as possible. The transference of the film from a cold solution to a warmer one, or vice-versa, subjects the gelatin layer to strain which is likely to result in reticulation. Recent experiments have shown that the excessive graininess of films processed in warm solutions is a mild form of reticulation although not immediately recognizable as such. The effect of a sudden change in temperature is at a maximum with swollen gelatin, hence, the desirability of preventing swelling at all stages of processing and hardening the film permanently as soon as possible.

Physical Development.—The process of development mistakenly known by this term consists in the use as a developer of a solution containing a silver salt in conjunction with a suitable reducing, i.e., developing, agent. The reducing agent results in the formation of metallic silver in a colloidal state which is precipitated upon the latent photographic image. Thus the image is formed as a result of the deposition of silver from the developing solution and not, as in the usual method of development, by the reduction of the exposed grains of silver halide in the emulsion to metallic silver.

So far as negative development is concerned, physical development is of interest chiefly as a means of obtaining an image of extremely fine grain. With physical development, the grain size of the image is largely independent of that of the emulsion. As applied to the development of transparencies, physical development is notable for the rich, velvety, transparency of the shadows and the unique bluish-black tones, while as a means of intensification it has the advantage of acting pro-

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sodium sulfate per quart of developer (45 grams per liter). The approximate times of development are:

80° F. (26.5° C.)	9½ minutes
85° F. (29.5° C.)	7 minutes
90° F. (32° C.)	5 minutes

portionally and unlike many other methods of intensification producing permanent results.[41]

Against these advantages must be set certain disadvantages: (1) the process is slow, (2) more than ordinary care and attention to detail is required, (3) there is less latitude in exposure, (4) there is less control over the contrast of the negative.

The most widely used method for negative development is that of Odell based upon earlier work by Luppo-Cramer.[42] Odell's method involves two operations: (1) preliminary treatment in a solution of potassium iodide, forming what is termed the "forebath"; and (2) development from twenty-five to thirty minutes in a diaminophenol-silver nitrate developer followed by fixation in the usual acid fixing and hardening bath. According to Odell, no increase in exposure is required if the forebath is used.

The forebath is prepared as follows:

Potassium iodide	5 gm.	80 gr.
Sodium sulfite (des.)	12.5 gm.	195 gr.
Water to	500 cc.	16 oz.

Use without dilution. The film or plate is immersed in the forebath for three to four minutes and then rinsed thoroughly in two or three changes of water. The forebath solution may be used several times before being discarded.

The developer is prepared as follows:

Sodium sulfite (des.)	50 gm.	1 oz.	300 gr.
Silver nitrate (crystals)	8 gm.	120 gr.	
Hypo crystals (fresh prismatic)	80 gm.	2 oz.	300 gr.
Water to	500 cc.	16 oz.	

This solution is quite stable but should be kept from strong light. To mix, dissolve the sulfite in 8 ounces of water (250 cc.) and silver nitrate in 7 ounces (200 cc.). Add the silver solution to the sulfite solution and stir until the white precipitate is completely dissolved. Finally, add the hypo and stir until dissolved.

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[41] See *J. Soc. Mot. Pict. Eng.*, **17** (1931), 1001.

[42] Odell, *Camera* (Phila.), **46** (1933), 217. Photominiature: Physical Development. *Brit. J. Phot.*, **80** (1933), 286, 303. Luppo-Cramer, *Phot. Ind.*, 1917, 401.

ODELL—After Four Years of Physical Development. Camera (Phila.), 54 (1937), 145. Brit. J. Phot., **84** (1937), 310.

The developer should be prepared as required immediately before use as it does not keep.

Silver stock solution	100 cc.	3¼ oz.
Water to	500 cc.	16 oz.
Diaminophenol (dry)	¾ gm.	12 gr.

Stir until the diaminophenol is completely dissolved. This solution must be used in vessels of either glass, bakelite or other synthetic resin material, stainless steel or chromium plated metals. The silver will deposit on other substances weakening the developer.

The time of development, with constant agitation, is from twenty-five to thirty minutes at a temperature of 65° F. The importance of thorough agitation can hardly be overestimated; it is one of the most important factors in securing clear negatives of good density and contrast. The higher the temperature of the developer the more important is thorough agitation; however, physical development is not advisable at a temperature higher than 70° F. (21° C.).

After development, the film, or plate, is rinsed briefly in water and fixed in the usual acid fixing and hardening bath.

Horizontal Development.—This term is applied to a method of development advocated by Walter [43] in 1907, in dealing with negatives of contrasty subjects. The tray is made absolutely level, the developing solution poured over the plate or film *and left undisturbed until development is complete.* Sensitometric studies of the results obtained have been made by Mees and Wratten and by Heydecker.[44] The latter using a dilute glycin developer requiring 50 minutes to develop, found that the lower densities—those lying in the toe of the *D*-log *E* curve—are increased, while the higher densities are depressed and the shoulder of the curve begins at a lower density.

The developing tray must be absolutely level and the solution totally undisturbed during development if the end sought is to be attained. The theory of this method of development is that those portions of the negative which have received the most exposure develop first and release free bromide which, owing to the stagnant developer, remains in the vicinity where it is created and serves to retard development thus

[43] Walter, *Brit. J. Phot.*, **54** (1907), 884.

[44] Mees and Wratten, *Brit. J. Phot.*, **54** (1907), 172. Heydecker, *Brit. J. Phot.*, **70** (1923), 635.

Knapp—Knapp System of Development. Brit. J. Phot., **80** (1933), 191.

preventing the highlights from attaining their full density, while the lower densities are being fully developed.

Contrast Developers.—A developing solution designed for maximum contrast with process materials must produce density readily and be free from any tendency to fog even with prolonged development. At the present time, this condition is most nearly satisfied by concentrated metol-hydroquinone or hydroquinone developers with a high concentration of alkali restrained with potassium bromide. To secure the high alkalinity necessary for rapid development, the alkaline carbonates are frequently replaced by the caustic alkalis, such as sodium or potassium hydroxide, while for certain sensitive materials the use of para-formaldehyde is recommended. Developers of this type should act rapidly so that full density is produced before the restraining effect of the potassium bromide is overcome.

From a practical standpoint, it should be noticed that developers of this type should not be used at temperatures below 60° F. or above 70° F. Also, to prevent stain, the negative should be rinsed well between development and fixing.[45]

Combined Developing and Fixing.—While considerable attention has been devoted to the subject of combined developing and fixing, a thoroughly practical and reliable method has not yet been developed. Usually considerable overexposure is necessary and besides there are two other drawbacks: (1) development and fixation are unequally affected by temperature so that it is difficult to secure the proper balance between the two except at a particular temperature; (2) with the exception of pyrocatechin the activity of all organic developing agents is affected by hypo resulting in staining of the image and the formation of dichroic fog.

The most reliable formulas for use with present day sensitive materials are probably those of Lumiere and Seyewetz.[46]

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[45] "Negative Developers for Contrast," Southworth, *Brit. J. Phot.*, **75** (1928), 680, 706.

[46] Lumiere and Seyewetz, *Brit. J. Phot.*, **71** (1925), 44.

CHAPTER XV

FIXING, WASHING AND DRYING

The Chemistry of Fixation.—The removal of the silver halide remaining in the emulsion after development is termed fixing. Only a few substances are capable of converting the silver halides into soluble compounds and of these sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$), commonly termed hypo and sometimes incorrectly referred to as sodium hyposulfite, is the only one of practical utility.[1]

The precise chemical reactions involved in the fixing process are still obscure.[2] Thiosulfate ions undoubtedly combine with silver ions to form various soluble complex ions, as for example

$$\begin{aligned}&AgBr + 3Na_2S_2O_3 \rightarrow NaBr + Na_5Ag(S_2O_3)_3,\\&AgBr + 2Na_2S_2O_3 \rightarrow NaBr + Na_3Ag(S_2O_3)_2,\\&2NaBr + 3Na_2S_2O_3 \rightarrow 2NaBr + Na_4Ag_2(S_2O_3)_3.\end{aligned}$$

A number of such complexes are possible and in a used fixing bath it is probable that several are present in equilibrium, the particular ones present depending upon the relative concentrations of thiosulfate and silver. It is possible that in a fixing bath containing only a small amount of silver the complexes may contain even more thiosulfate than those in the equations, while in a used fixing bath the slightly soluble $NaAgS_2O_3$ may be found.

Since these insoluble, or slightly soluble, complexes are unstable, they will, if left in the film, decompose in time, producing a silver sulfide stain.

[1] The sulphocyanides as fixing agents. Cf. Piper, *Brit. J. Phot.,* **61** (1914), 458, 511.

[2] Herschel, *Edinburgh Phil. Jl.,* **1** (1819), 8, 396. Baines, *Phot. Jl.,* **69** (1929), 314. Sheppard, Elliott and Sweet, *J. Frank. Inst.,* **195** (1923), 45.

BAINES—Chemistry of Fixation. Phot. J., 69 (1929), 314–317.
RENWICK—Principles and Practice of Fixation. Phot. J., 69 (1929), 310–314.
SHAW—Fixation and Permanence. Brit. J. Phot., 80 (1933), 214.
SHEPPARD AND MEES—Theory of Fixation. Phot. J., 46 (1906), 235.
WARWICK—The Laws of Fixation. Amer. Phot., 11 (1917), 585.

Fixing Baths.--While a solution of hypo will dissolve silver halide, it does not form a satisfactory fixing bath because the developing solution on the surface of the films or prints, when placed in the fixing bath, oxidizes and causes stain. Staining may be prevented, however, if a substance, such as sodium sulfite, which tends to prevent the oxidation of the developer, is added to the fixing bath. The addition of a weak acid neutralizes the alkali introduced by the developer, maintains the bath in an acid condition, and assists the sodium sulfite in preventing the oxidation of the developing agent thus greatly increasing the period over which the fixing bath may be used without danger of staining.

The most convenient method of preparing an acid fixing bath is by the use of an acid sulfite such as sodium bisulfite ($NaHSO_3$).

Hypo	8 oz.	250 gm.
Sodium sulfite	145 gr.	10 "
Sodium bisulfite	365 gr.	25 "
Water to make	32 oz.	1000 cc.

The sodium sulfite is added to prevent possible precipitation in hot weather.

With use, the reserve acidity is soon neutralized by the developer brought over into the fixing bath and it becomes necessary either to discard the bath or to add a 25 per cent solution of sodium bisulfite in sufficient quantity to render the bath acid.

Acid fixing baths of this type are satisfactory when it is not necessary to harden the gelatin or if a hardening stop bath is employed after developing and prior to fixing.

Acid Fixing and Hardening Baths.—A combined acid fixing and hardening bath contains the following ingredients: (1) a solvent of silver halide, (2) an anti-staining agent, (3) a preservative, and (4) a hardening agent.

These ingredients ordinarily are hypo; an organic acid, usually acetic; sodium sulfite and alum.

It is the function of the acid to neutralize the alkali in the developer carried over on the film preventing oxidation thus keeping the bath clear and free from staining tendencies. The addition of acid to a solution of hypo, decomposes the hypo forming sulfur and sulfurous acid, and destroys the fixing power of the bath. To prevent the precipitation of sulfur, sodium sulfite, which combines with sulfur to form hypo, is added. An acid fixing bath is thus rendered stable by the sulfite, which also assists in preventing the oxidation of the developing solution carried over into the fixing bath.

Organic acids, such as acetic, citric and oxalic, are better adapted to these requirements than inorganic acids, such as sulfuric or hydrochloric, because being less disassociated they do not tend to precipitate sulfur from a solution of hypo so readily. Solid organic acids, on the other hand, produce with aluminum salts (such as the alums) complex aluminum ions which are not satisfactory as hardening agents. The acid sulfites, such as sodium bisulfite and potassium metabisulfite, are not suitable for a fixing bath containing alum, as the reserve acidity is not sufficient to prevent the precipitation of aluminum sulfite upon the addition of alkali.

Hardening of the gelatin may be produced by salts of aluminum, chromium, and iron, by formaldehyde, tannin, and by quinones and quinonid bodies. Of these only the alums and formaldehydes are suitable for use in fixing baths. The hardening produced with alum is due to the hydrolytic separation of the alum into hydrous oxide and free acid,

$$Al_2(SO_4)_3 + 3H_2O \leftrightarrows Al_2O_3 + 3H_2SO_4.$$

The alumina, or other oxide, combines with the gelatin probably as an absorption complex and is retained on washing in hot water.

Crabtree and Russell—Some Properties of Chrome Alum Stop Baths and Fixing Baths: I. Chrome Alum Stop Baths. II. Chrome Alum Fixing Baths. J. Soc. Mot. Pict. Eng., **15** (1930), 483–512, 667–700.

Crabtree and Russell—Acid Hardening Fixing Composition. (Eastman Kodak Co.) U.S.P. 2,063,297 of 25.10.34.

Elliott, Sheppard and Sweet—The Chemistry of the Acid Fixing Bath. J. Frank. Inst., **196** (1923), 45.

Kieser—Chemistry of Fixing Baths. Phot. Ind., **32** (1934), 696; S.&I.P., (II), **5** (1934), 252.

Luther and Rommler—Chemistry of the Fixing Bath. Phot. Ind. (1928), 626.

Meuhler—Liquid Hardener Solutions. (Eastman Kodak Co.) U.S.P. 1,981,426 of 18.4.33.

Russell—Acid Hardening Fixing Bath. (Eastman Kodak Co.) U.S.P. 1,981,391 of 27.9.32.

Russell and Crabtree—An Improved Potassium Alum Fixing Bath Containing Boric Acid. J. Soc. Mot. Pict. Eng., **21** (1933), 137.

Staud and Briggs—Hardening Photographic Gelatin Emulsions and Gelatin Solutions. Kodak Ltd. B.P. 444,289 (4.8.34).

Sheppard—Hardening Photographic Gelatin Emulsion and Solutions. (Eastman Kodak Co.) U.S.P. 2,059,817 of 27.9.34.

The hardening action of formaldehyde is due probably to the interaction of the amino groups of the gelatin with formaldehyde resulting in the formation of an insoluble compound of undetermined composition.[3]

The following is a widely used formula for an acid fixing and hardening bath using potassium alum:

	Avoirdupois	Metric
Water	64 ounces	2.0 liters
Hypo	16 ounces	480.0 grams

When thoroughly dissolved, add the following hardening solution [4] slowly to the cool hypo solution while stirring the latter rapidly:

	Avoirdupois	Metric
Water (about 125° F.) (52° C.)	5 ounces	160.0 cc.
Sodium sulfite, desiccated	1 ounce	30.0 grams
Acetic acid (28% pure)	3 ounces	96.0 cc.
Potassium alum	1 ounce	30.0 grams

The period over which the hardening properties and the sludge-free life of a potassium alum fixing bath are maintained is greatly increased by the addition of boric acid, or a compound of boron, such as borax.[5]

The following formula is recommended:

Acid Hardening Fixing Bath [6]

	Avoirdupois	Metric
Water (about 125° F.) (52° C.)	20 ounces	600.0 cc.
Sodium thiosulfate (hypo)	8 ounces	240.0 grams
Sodium sulfite, desiccated	½ ounce	15.0 grams
Acetic acid (28% pure)	1½ fluid oz.	48.0 cc.
Boric acid, crystals	¼ ounce	7.5 grams
Potassium alum	½ ounce	15.0 grams
Cold water to make	32 ounces	1.0 liter

When rapid fixing is desired, it is preferable to increase the hypo concentration to 12 ounces in 32 ounces (360 grams to 1 liter).

Chrome Alum Fixing Baths.—A properly compounded chrome alum fixing bath hardens gelatin more completely than one of potassium alum, but its hardening properties fall off more rapidly, unless acid is added from time to time to maintain the proper acidity. Chrome alum fixing baths are desirable when processing at high temperature, if the wash water is warm, or if it is necessary to dry rapidly at high temperature. Except under such conditions, potassium alum baths are usually more satisfactory owing (1) to their longer life and (2) because chrome alum baths when partially exhausted may harden the surface of the gelatin and not the underlying layers, which would tend to cause reticulation.

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[3] Sheppard, *Photography as a Scientific Implement,* p. 138.

[4] Eastman formula, F1.

[5] Russell and Crabtree, *J. Soc. Mot. Pict. Eng.,* **21** (1933), 139.

[6] Eastman formula, F5.

Chrome Alum Fixing Bath[7]

	Avoirdupois		Metric
Solution *A*			
Sodium thiosulfate (hypo) . . .	2	pounds	960.0 grams
Sodium sulfite, desiccated	1	oz. 290 gr.	50.0 grams
Water to make	96	ounces	3.0 liters
Solution *B*			
Water	20	ounces	600.0 cc.
Sodium sulfite, desiccated	290	grains	20.0 grams
Sulfuric acid, 5%	5	fluid ozs.	160.0 cc.
Potassium chrome alum	4¼	ounces	218.0 grams
Water to make	32	ounces	1.0 liter

Cool the solutions to 70° F. (21° C.) and add solution *B* slowly to solution *A* while stirring the latter thoroughly.

Solution *B* should not be kept as a stock solution as the hardening properties become less with age.

Usually, the hardening properties of a chrome alum fixing bath are destroyed by the addition of developer before the bath is exhausted. The addition of sulfuric acid from time to time, in quantities sufficient to maintain the proper degree of acidity lengthens the useful life of the bath. The quantity of sulfuric acid required may be found by titrating about one ounce (30 cc.) of the fixing bath with 2.5 per cent sulfuric acid, using brom-phenol-blue as the indicator. Sufficient acid should be added to make the solution yellow. The quantity of acid necessary to bring the fixing bath to the proper acidity can be calculated from the amount added to the test solution.

Preparation of Fixing Solutions.—No difficulty is usually experienced when mixing a plain hypo solution. When mixing a quantity of solution in a tank, the filter bag should be used and the hypo dissolved in warm water, because the temperature drops considerably while the hypo is dissolving. If a scum forms on the surface of the solution on standing, it should be removed by drawing the edge of a towel or blotter, or a cheesecloth skimmer, across the surface.

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[7] Eastman formula, F-23.

In preparing an acid fixing bath which contains either sodium bisulfite, or potassium metabisulfite, care should be taken not to add these to the warm hypo solution; otherwise sulfur will be precipitated and the bath rendered milky. The solution should be quite cold (not above 70° F. (21° C.) when mixed.

In preparing an acid fixing and hardening bath, the order of mixing the acid hardener is important. When mixing in one vessel, first dissolve the sulfite in warm water (125° F. (52° C.); then add the acid; and, finally, the potassium alum. Another method is to dissolve the alum and sulfite in separate solutions, cool, add the acid to the sulfite solution, and then add the alum solution.[8]

The hypo should be cool and completely dissolved before adding the hardener, or sulfur is likely to be precipitated.

Fixing baths containing chrome alum as the hardening agent generally have sulfuric acid as the active acid. Usually, no difficulty is experienced in preparing such baths, provided care is taken in adding the sulfuric acid to the chrome alum solution. The acid should be added slowly, while the solution is vigorously stirred, in order to insure thorough mixing, since the acid is heavy and will sink to the bottom if not well mixed. Water should never be added to sulfuric acid or the solution may boil and spatter acid on the hands or face, causing serious burns.

The Hardening of Gelatin in Fixing Baths.—The degree of hardening produced in an acid fixing and hardening bath depends upon:

1. *The composition of the bath.* Under given conditions, the degree of hardening produced in an acid fixing and hardening bath employing potassium alum depends upon the pH value of the bath, which in turn is determined by the relative proportions of acid, sulfite, and alum. For each concentration of acid, there is a definite quantity of sulfite, which produces the maximum hardening with a given quantity of alum. An increase in the amount of alum results in a higher degree of

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[8] To make 28 per cent acetic acid from glacial acetic acid, dilute three parts of glacial acid with eight parts of water.

In the case of formulas requiring boric acid, the crystalline form should be used. Powdered boric acid dissolves only with great difficulty, and its use should be avoided.

hardening, but increases the tendency of the bath to sludge upon the addition of developer.[9]

2. *The time of fixing.* The degree of hardening increases with the time of fixing up to a maximum which depends upon the bath and the conditions of fixing. The time required for maximum hardening may vary from three to fifteen minutes, depending upon the fixing bath and the thickness of the gelatin layer.

3. *The alkalinity of the film when placed in the fixing bath.* The quantity of alkali in the film when it is placed in the fixing bath is one of the major factors in the degree of hardening produced in an acid fixing and hardening bath. Film which is strongly alkaline is not as thoroughly hardened as that which has been well washed before fixing. For maximum hardening, therefore, film should be well washed after development, or placed in a stop bath, before being transferred to the fixing bath.

4. *The temperature of the fixing and hardening bath.* The degree of hardening increases slightly with the temperature of the fixing bath, but if the temperature of the developer and rinse water, or stop bath, has increased at the same time, the film will not be as thoroughly hardened because of the increased swelling of the gelatin when placed in the fixing bath. The temperature of the fixing bath and other processing solutions should be maintained between 65 and 70 degrees F. (18° to 20° C.) for maximum hardening.

Effect of Use on a Fixing Bath.—The major changes taking place in a fixing bath as it is exhausted through use are as follows:

1. *The concentration of hypo is reduced.* This reduces the amount available for fixing and tends more and more to form complex ions of silver thiosulfate which are either slightly soluble, or insoluble, in water.

2. *Sodium silver thiosulfate, sodium bromide (and iodide in the case of sensitive materials containing iodide) accumulate in the bath.* The exact formula of the silver compound is not definitely known but is probably $Na_4Ag_2(S_2O_3)_3$.[10]

The fixing properties of the bath are not materially affected by the silver compound—except to the extent to which it represents a reduction of the original hypo concentration—but the accumulation of alkaline halide, particularly potassium iodide, greatly retards the rate of fixing and materially reduces the fixing properties of the bath.[11] The presence of even a small amount of iodide is sufficient to prevent thorough fixation, although the amount of silver present in the fixing bath is far below the saturation point.

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[9] Crabtree and Hartt, *Trans. Soc. M. P. Eng.*, 13 (1929), 364.

[10] Barth, *Z. Phys. Chem.*, 9 (1912), 218.

3. *The hardening properties are reduced as a result of the gradual neutralization of the free acid in the fixing bath by the alkali carried over on the film.* When the acidity of the bath has been reduced beyond a certain value, usually near the neutral point, a sludge of aluminum sulfite forms and the hardening properties are destroyed. The amount of alum adsorbed, or otherwise removed from the bath in hardening, is negligible and is without practical effect on the hardening properties of the bath.[12]

The limits to which a fixing bath may be used, with the assurance of thorough fixation, depends on (1) its ability to convert the silver halides into soluble silver sodium thiosulfate compounds and (2) its ability to harden the gelatin sufficiently.

When sensitive materials containing silver iodide are fixed, the saturation point of solutions of hypo is fixed by the amount of silver iodide present. The presence of silver iodide above the saturation point prevents complete fixation, even if the amount of dissolved silver is much below the saturation point.[13]

The investigations of Busch and Lehrmann indicate that in a solution of hypo containing 150 gm. to 1000 cc. the bath is exhausted when the silver content reaches 0.6–0.7 per cent. If a negative emulsion is assumed to contain 0.10 gram silver per square meter, then for practical purposes each ounce of fixing bath should be sufficient for approximately 15 square inches of plate or film.

In practice, the time of clearance—which is a direct indication of the time required for fixing—is so greatly increased by the restraining effect of the accumulated alkaline halides that the bath is discarded before the limit is reached because of the time required to clear. As a general rule, a fixing bath should be discarded when the time of clearing is double that of a fresh solution, assuming in each case the same sensitive material.

With a potassium alum fixing bath containing boric acid, the harden-

[11] Busch and Lehrmann, *Brit. J. Phot.*, **75** (1927), 91.

[12] Crabtree and Hartt, *Trans. Soc. Mot. Pict. Eng.*, **18** (1929), 364.

[13] Busch and Lehrmann, loc. cit.

LEHMANN AND BUSCH—Fixing Baths and their Better Utilization. Kinotech Jahrbuch, 1925/26, 114–130; S.&I.P., **6** (1926), 148.

ing properties under normal conditions are not substantially reduced before the bath is exhausted. With potassium alum fixing baths which do not contain boric acid, and more particularly with chrome alum fixing baths the loss of hardening properties usually makes it necessary to discard the bath before it is exhausted, unless the acidity is maintained by the addition of acid from time to time.

The Testing of Used Fixing Baths.—The amount of silver present in a used fixing bath may be determined by adding a solution of sodium sulfide to a sample of the bath diluted with water. A brown precipitate is produced, the depth of which depends upon the amount of silver. The quantity of silver present may be determined by comparing the color of the test solution—held before an illuminated screen in a glass tube—with other tubes containing a known concentration of silver sulfide.

There are two drawbacks to this method of testing a fixing bath: (1) the standardized comparison solutions do not keep well; (2) the color of the precipitate from a fixing bath varies with the acidity, the sulfide, and alum content of the bath, as well as the quantity of silver present.

The last-mentioned drawback may be overcome by using the following test solutions:

Solution A

Citric acid	9 grams	1¼ ounces
Sodium citrate	100 "	13 "
Water to make	1000 cc.	128 "

Solution B

Gelatine	4 grams	½ ounce
Water to	1000 cc.	128 ounces
Clove oil (a few drops for preservation)		

Soak the gelatin in a small amount of water until well swollen, then heat gently, stirring until all is in solution; dilute to proper volume with water and pour into a bottle; add the clove oil and shake a few times.

Solution C

Sodium sulfide (CP Crystals)	10 grams	1 ounce
Sodium sulfite (desiccated)	6 "	260 grains
Water to	100 cc.	10 ounces

A sample of the fixing bath is measured out with a 2 cc. pipette and allowed to drain into a 50-cc. graduated cylinder. Five cubic centimeters of solution *A* are added, and then 5 cc. of solution *B* after which the cylinder is filled to the 50-cc. mark with water. Add 1 cc. of solution *C* and compare the opacity of the resulting precipitate with a standardized solution containing a known quantity of silver.

The concentration of silver in a sample of the fixing bath to which the testing solution has been added may be found by measuring the opacity of the precipitate. An instrument known as the Argentometer, employing a photronic cell, has been introduced by the Eastman Kodak Company for making such measurements quickly and conveniently.[14]

The following method based upon the formation of a precipitate of silver iodide has also been recommended for determining when a fixing bath is exhausted:

Withdraw 2½ ounces (100 cc.) of the fixing bath and add ¼ ounce (10 cc.) of a 4 per cent solution of potassium iodide. The bath may be regarded as exhausted if a yellow precipitate is formed on standing.

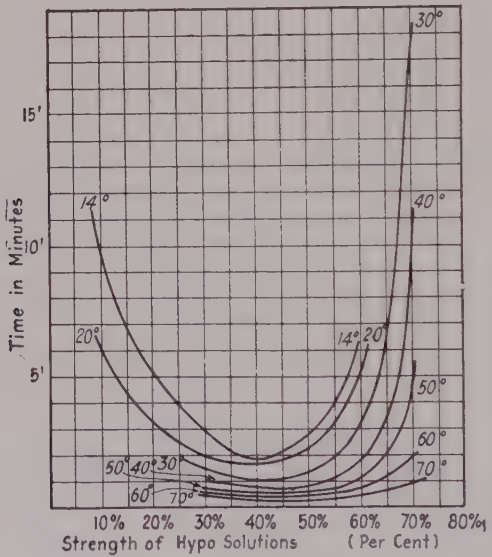

Fig. 176. Influence of Concentration of Hypo on Time of Fixation

Another method suggested frequently is as follows: immerse a strip of film, or bromide paper, in the fixing bath until clear, then wash for several minutes and place in a 1 per cent solution of sodium sulfide.

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[14] "The Argentometer—An Apparatus for Testing for Silver in a Fixing Bath," W. J. Weyerts and K. C. D. Hickman. *Brit. J. Phot.*, **82** (1935), 739.

The appearance of a brown discoloration indicates the presence of silver halide due to imperfect fixation.

The Time of Fixing.—The time required for the conversion of the silver halide into soluble complexes of sodium silver thiosulfate depends upon a number of factors:

1. *The nature and the thickness of the emulsion.* In general, fine-grain emulsions, such as those employed for positive printing, fix much more rapidly than negative emulsions which are composed of larger grains. Emulsions containing silver iodide fix more slowly than those of silver bromide, and these in turn more slowly than emulsions of silver chloride. A thickly coated material requires a longer time to fix than a thin one, if both emulsions are of the same general character.

2. *The nature and degree of exhaustion of the fixing bath.* The rate of fixing varies with the concentration of hypo, generally increasing up to a concentration of 30 to 40 per cent, and then decreasing (Fig. 176). The concentration at which the maximum rate of fixing is obtained depends in part upon the nature of the emulsion.

The addition of ammonium chloride to a plain hypo solution (not above 70° F.) increases the rate of fixing, but fixing baths of this type may not be so thoroughly exhausted as an acid fixing and hardening bath.[15] The effect varies with the amount of ammonium chloride added and the concentration of the hypo solution (Fig. 177).

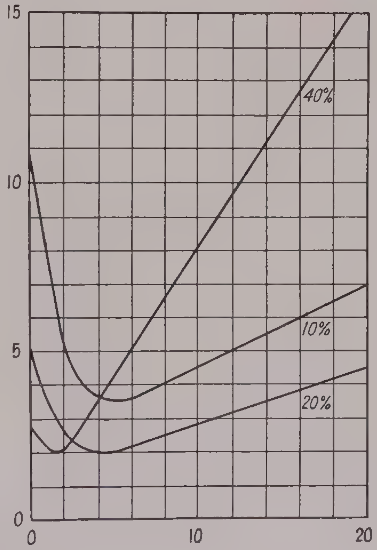

FIG. 177. Influence of Ammonium Chloride on the Time of Fixation.

The time required for fixing increases as the solution becomes exhausted owing (1) to the lower concentration of hypo and (2) to the restraining effect of the alkaline halides which accumulate in the bath.[16]

[15] Lumiere and Seyewetz, *Bull. Soc. franç. Phot.*, 1908, 217. Piper, *Brit. J. Phot.*, **61** (1914), 193, 437, 458, 511; **62** (1915), 364. Agfa, B.P. 25,869 of 1906.

[16] Strauss, *Phot. Ind.*, **23** (1925), 911. Crabtree and Ross, *Amer. Annual of Phot.*, 1927, 159.

3. *The temperature of the fixing bath.* The effect of temperature varies with the concentration of hypo (Fig. 178). At temperatures above 70°F. (21° C.) an acid fixing and hardening bath tends to sulfurize, and the degree of hardening is reduced, as the gelatin swells excessively before the hardening action becomes effective.

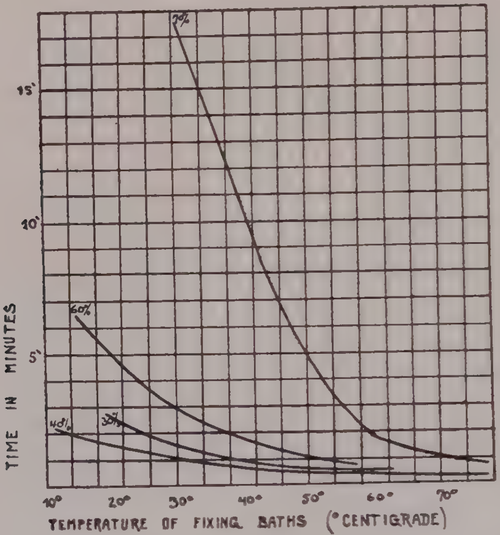

FIG. 178. Influence of Temperature on Time of Fixation

4. *The degree of agitation.* Agitation reduces the time required in fixing, but the effect is much less with fine-grain positive materials than with negative emulsions of coarser grain and more thickly coated.

Silver Recovery.—There are several methods by which the silver in a used fixing bath may be recovered; usually, however, the financial return is hardly sufficient to justify the expense and labor involved, except when dealing with large volumes of fixing bath.[17]

Silver Recovery with Sodium Sulfide. This is one of the most

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[17] Bibliography on processes of silver recovery and resume of methods. Crabtree and Ross, *American Annual of Photography*, 41 (1927), 159.

LUMIERE AND SEYEWETZ—The Time of Fixing of Developing Papers. Brit. J. Phot., 71 (1924), 108; Bull. Soc. franc. Phot. (1924), p. 31.
LUMIERE AND SEYEWETZ—The Fixing of Photographic Negatives. Rev. franc. Phot., 5 (1924), 61.
PIPER—The Rate of Fixing. Brit. J. Phot., 60 (1913), 59.
WARWICK—The Fixation of Prints. Amer. Phot., 11 (1917), 639.

satisfactory methods of precipitating the silver in a used fixing bath as it is rapid and economical, but acid fixing baths must first be neutralized with caustic soda to prevent unpleasant fumes of hydrogen sulfide.

The chemistry of the reaction is as follows:

$$Na_2S + Na_4Ag_2(S_2O_3)_3 = Ag_2S + Na_2S_2O_3.$$

Proceed as follows: Prepare a solution of caustic soda by dissolving 2 lbs. of commercial caustic soda in one gallon of cold water (240 grams in 1000 cc.).

Add one ounce of the solution of caustic soda to each gallon of the used fixing bath, stir well and test with *red* litmus paper. If the litmus paper does not turn blue, add more caustic soda until it does. Finally, add 1/5 oz. of caustic soda per gallon of fixing bath to assure reserve alkalinity.

The solution of sodium sulfide is prepared by dissolving two lbs. in one gallon of water (240 grams to 1000 cc.). This solution should not be prepared in close proximity to sensitized materials.

Add one ounce of this solution to each gallon of the neutralized fixing bath (7.5 cc. to 1000 cc.). Stir well and allow to stand for a few minutes. To determine if the silver has been completely precipitated, withdraw a small volume of the solution, filter, and add a little of the sodium sulfide solution. If a dark precipitate forms, more of the sodium sulfide solution should be added to the fixing bath until the test gives a clear solution.

Allow ten to twelve hours for the sludge of silver sulfide to settle out and drain off the clear liquid.

Silver Recovery With Zinc. The reaction taking place when zinc is added to a used hypo bath may be written as follows:

$$Na_4Ag_2(S_2O_3)_3 + Zn = 2Ag + ZnS_2O_3 + 2Na_2S_2O_3.$$

The amount of silver recovered is less than with sulfide and precipitation is not as rapid, but no objectionable odors are produced.

Although silver is precipitated by zinc from either acid or alkaline

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Arens and Eggert—Recovery of Silver from Used Fixing Baths. Phot. Ind., **34** (1936), 1011, 1040; S.&I.P. (II), **7** (1936), 402.

Hickman and Hyndman—Automatic Silver Recovery from Hypo. Brit. J. Phot., **74** (1927), 683.

Crabtree and Ross—Recovery of Silver from Exhausted Fixing Baths. Brit. J. Phot., **73** (1926), 522–526.

fixing baths, the best results are obtained if the bath is acid. Most discarded fixing and hardening baths are slightly acid; if tests with litmus paper show a particular bath to be alkaline, glacial acetic acid should be added until the bath is distinctly acid.

Either zinc dust, granulated, or sheet zinc may be used, but the rate of precipitation is very slow with the last two.

Using zinc dust, add ⅔ of an ounce to each gallon of fixing bath (5 grams per liter) while stirring constantly. Continue to stir the bath for three or four minutes and then allow to stand for 16 to 24 hours. Complete precipitation of the silver may be determined by testing with sodium sulphide.

After draining away the clear solution, the sludge should be removed, filtered if necessary, and dried.[18]

Electrolytic Methods of Recovery. The silver in a used fixing bath may also be recovered by electrolysis. An electric current passing between electrodes immersed in the fixing bath will cause the silver to separate either as metallic silver or as a suspension of silver sulfide, depending upon the difference in potential. Elaborate machinery for recovering silver from fixing baths has been developed and is used widely in motion picture processing laboratories. The silver is recovered as metallic silver and, as the processes employed may be used to remove silver from a fixing bath while in use, it retains its fixing and hardening properties longer.[19] The factor of expense places such equipment beyond the resources of all but the larger laboratories.

Silver recovery units of separated copper and zinc plates forming an electrolytic couple are available commercially. When placed in a fixing bath containing silver, a current flows through the bath from the zinc to the copper; if the potential is about 0.7 volts, metallic silver is deposited on the copper plate. These units produce a sludge if placed in a fixing bath when in use but form a very convenient means of recovering silver from discarded solutions as they require no particular attention. Large containers are necessary for the used baths, however, as from one to two weeks are required for the maximum recovery.

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[18] The sulfides of lead, iron and hydrogen and sodium hydrosulfite or sodium formaldehyde-sulfoxylate may be used for the recovery of silver from used fixing baths but are no more efficient and relatively more expensive than sodium sulfide or zinc.

[19] Hickman, Sanford and Weyerts, *J. Soc. Mot. Pict. Eng.*, **17** (1931), 568. Hickman, *J. Soc. Mot. Pict. Eng.*, **17** (1931), 591.

PART II. WASHING

The removal of the hypo and soluble by-products remaining in the film after fixation is essential to the permanency of the image, for if left in the gelatin they decompose, producing colored stains and causing the image to fade. Ordinarily, the elimination of these by-products is accomplished by simply washing in water. Certain substances known as hypo eliminators are used under certain conditions to reduce the time of washing but offer no real advantage.

Water Supply.—In general, water as supplied for human use is suitable for the washing of photographic materials. Water containing vegetable, or animal matter in solution, or dissolved salts, such as the bicarbonates, chlorides and sulphates of calcium, magnesium, sodium and potassium may cause trouble by producing a scum on the surface of the gelatin unless it is wiped carefully before drying.[20]

While salt water may be used for washing, the film should be washed for a short while—or passed through three changes of fresh water before drying.

Water containing grit, or other solid matter, should be filtered before use.

Washing Tanks.—Washing tanks vary in design and size according to the character of the sensitive material and are constructed of metal, wood, stone, hard rubber or plastic materials. Small tanks are less bulky and cumbersome if made of metal, hard rubber or plastic materials. Wood parafinned or coated with a waterproof paint, and stone are suitable for larger tanks which are permanently installed. The efficiency of a washing tank depends not only upon the time required to completely change the water in the tank but also upon the agitation of the water in the tank. Other things being equal, the smaller the tank the more efficient it is; consequently, the washing tank should not be larger than is actually required for the proper handling of the film. To ensure rapid renewal of the water in all parts of the tank, an inlet with a number of openings in various part of the tank is better than a single inlet. In small tanks, a single perforated pipe placed lengthwise along the bottom of the tank will result in good circulation, particularly if the water is allowed to overflow through openings along the sides. In large tanks, several such pipes equally spaced may be required for efficient washing. If good agitation of the water in the tank is provided, nothing is gained by siphoning the water from the bottom.

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[20] In extreme cases such water should be chemically treated before use. Most commercial methods of softening water are suitable (e.g., permuit) as is treatment with alum. See Matthews, G. E., and Crabtree, J. I., *Water Supply in Processing Motion Picture Film, J. Soc. Mot. Pict. Eng.,* **16** (1931), 437.

The time required to change the water in a tank may be determined by filling the tank with a dye, or with a solution of potassium permanganate, turning on the water, and noting the time required to clear the tank of the colored solution.

Time of Washing.—In general, hypo diffuses from the gelatin exponentially with time.[21] In other words, the quantity of hypo leaving the film at any moment is proportional to the quantity present at the same time.

Thus, for example, if for each minute of washing, one half of the hypo present leaves the film the amount originally present will be reduced to one-fourth in two minutes, one-eighth in three minutes, one sixteenth in four minutes and in twenty minutes the amount remaining will be only 1/1,000,000 of that originally present.

The rate at which the hypo diffuses from the gelatin layer depends upon the difference in the concentration of hypo in the gelatin and in the water in contact with it. The lower the concentration of hypo in the water in contact with the gelatin layer, the more rapid the diffusion of hypo from the gelatin. Thus the more rapidly the water in contact with the film is renewed and replaced with fresh, the less the time of washing necessary to reduce the amount of hypo by a given amount. The maximum rate of washing is obtained by spray. Experiments have shown that a plate, or film, held directly beneath a tap is washed in from five to six minutes.[22] In a tank, the time of washing depends primarily upon the time required to fill and empty the tank. The more often the water in the tank is changed the shorter the time of washing.

[21] Mees and Sheppard, *Investigations on the Theory of the Photographic Process,* 1903. Lumiere and Seyewetz, *Bull. Soc. franç. Phot.,* 1902, 251. Warwick, *Brit. J. Phot.,* **64** (1917), 261. Elsden, *Phot. Jl.,* **57** (1917), 90. Hickman and Spencer, *Phot. Jl.,* **62** (1922), 225.

[22] Hickman and Spencer, *Phot. Jl.,* **62** (1922), 225.

ELSDEN—The Theory and Practice of Washing. Phot. J., **57** (1917), 90; Brit. J. Phot., **64** (1917), 120.

HICKMAN AND SPENCER—Washing of Photographic Products. Phot. J., **62** (1922), 225; **63** (1923), 208; Brit. J. Phot., **69** (1922), 387, 400.

HICKMAN AND SPENCER—The Washing of Photographic Products, Parts IV, V, VI. Phot. J., **64** (1924), 539.

WARWICK—Scientific Washing of Negatives and Prints. Amer. Phot., **11** (1917), 317.

Since the object in washing is to reduce the hypo in the film to an amount which will ensure the stability of the image, it is evident that, for given conditions of washing, the time depends upon the amount of hypo originally present in the gelatin layer. For this reason, negative film, owing to its thicker coating, requires longer washing than positive materials.[23] Likewise gelatin which is excessively swollen from immersion in warm solutions, or a fixing bath which does not harden, absorbs more hypo and hence requires longer washing than that which has been properly hardened. It is essential, therefore, for rapid washing to prevent the undue swelling of the gelatin (1) by maintaining developing and fixing solutions at the proper temperature, (2) by using a fixing bath which hardens efficiently, and (3) by avoiding developing solutions which because of the time required for development allow the gelatin to swell excessively before it reaches the fixing bath.

Tests for Hypo.—Two common methods are used to detect the presence of sodium thiosulfate in photographic materials and roughly determine the thoroughness of washing:

(1) When the film is thought to be washed, it is lifted from the washing tray or tank and the surface water allowed to drain into 10 or 20 cc. of the following alkaline potassium permanganate solution:

	Avoirdupois	Metric
Potassium permanganate...........	7.5 grains	0.5 gram
Sodium hydroxide (caustic soda).....	15.0 grains	1.0 gram
Water (distilled) to make...........	32.0 oz.	1.0 liter

For use, take stock solution 1 part, water 20 parts. If a small percentage of hypo is present, the violet color will turn orange in about 30 seconds, and with larger concentrations of hypo the orange color will change to yellow.

Oxidizable organic matter, if present in the water, reacts with the permanganate solution and changes the color in the same manner as hypo. The water, therefore, should be tested as follows:

Add a quantity of water equal in volume to that of the wash water drained from the film to a second test solution prepared as above from pure water. If the sample to which tap water has been added remains a violet color, this indicates the absence of organic matter and it will be unnecessary to repeat the test. If the color is changed slightly by the tap water, the presence of hypo in the film will be shown by the relative color change of the two samples. For example, if the tap water sample turned orange, and wash water sample became yellow, it would indicate the presence of hypo; but if both samples remained the same shade, this would indicate the absence of hypo.

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[23] Papers constitute a special case.

A more sensitive test consists in placing strips of film in a solution of mercuric chloride, preferably one which also contains potassium bromide, and observing any turbidity which may develop in the solution. If sodium thiosulfate is present, it reacts with the mercuric chloride to form mercurous chloride which is relatively insoluble and causes a turbidity to appear in the solution. If no sodium thiosulfate or other reducing agent is present, the solution remains clear although the silver image is bleached white.

The test solution is prepared as follows:

Mercuric chloride	365 gr.	25 gm.
Potassium bromide	365 gr.	25 gm.
Water to make	32 oz.	1000 cc.

To make the test, place a piece of the washed film about 1 inch square, in a test tube and add about 10 cc. of the test solution. The appearance of a milky precipitate in 10 to 15 minutes is an indication of the presence of hypo.[24]

A very sensitive test is available in a solution of iodine and starch.[25] Two stock solutions are made:

A.	Iodide	4 oz.	100 gm.
	Potassium iodide	4 oz.	100 gm.
	Water to	10 oz.	1000 cc.
B.	Sodium azide	4 oz.	100 gm.
	Water to	10 oz.	1000 cc.

A starch mixture is also prepared by mixing 90 grains (6 gm.) of soluble starch with cold water and adding this to 7 oz. (200 cc.) of boiling water. On cooling, dilute to 25 ounces (800 cc.) and add 60 minims of Solution *A* (3.25 cc.) and 235 minims of Solution *B* (13 cc.) diluting finally to a total of 35 ounces (1000 cc.). This stock solution keeps well and for use is diluted with one hundred parts of water. If a small quantity of this solution is placed in a test tube and the drippings from a negative or print are collected in the tube, the blue color of the solution will be immediately discharged if hypo is present.

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[24] Crabtree and Ross, *J. Soc. Mot. Pict. Eng.*, **14** (1930), 419.

[25] Clark and Jelley, *Brit. J. Phot.*, **76** (1929), 714.

Hypo Eliminators.—Many substances have been recommended as a means of reducing the washing time by converting the hypo into compounds which are more soluble in water. Among the substances which have been recommended, for this purpose are lead acetate, hypochloride of zinc, hydrogen peroxide, ammonium persulfate, potassium permanganate, potassium percarbonate, sodium bicarbonate and caustic soda.[26]

A. E. Amor[27] gives details of some investigations on the action of caustic soda at various concentrations and on ammonium persulphate, hydrogen peroxide and patassium permanganate. A 0.2 per cent solution of caustic soda and potassium persulphate were found to be the two most efficient eliminators but neither represents a decided superiority over washing in running water provided that this is properly used. The infinitesimal trace of hypo adsorbed by the gelatin and silver image can be displaced a little more quickly by the use of a mildly alkaline bath, shortening the time of washing by five or ten per cent. There is no saving of time, however, since a minute's longer washing would do as much as an eliminator bath of the same duration. Altogether, then, it appears that there is no advantage whatsoever in the use of the so-called "eliminators" of hypo. Plenty of water properly applied is still the secret of thorough hypo elimination.

It is open to question whether the use of such agents really result in a saving in time, or is permissible if permanency is a consideration. The evidence available indicates that a period of efficient washing equal to that in the hypo eliminator is as efficient as a means of removing hypo from the gelatin film.

PART III. DRYING

Removing Surplus Water.—The problem in drying is to reduce the water content of the film as removed from the washing tank until it is in equilibrium with the moisture content of the air in which the negative is handled or stored. This must be accomplished without causing distortion of the image, an alteration in density, and without affecting the film base. The first step in drying is to remove the surface water adhering to the gelatin. Since the time of drying, under given conditions, depends upon the amount of water to be evaporated, the removal of the water on the surface of the gelatin film reduces the time of drying. It also serves to remove grit and slime which may have become attached to the film, and to prevent the formation of drops of water which result in drying marks due to the difference in the time required to dry.

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[26] Lumiere and Seyewetz, *Bull. Soc. franç. Phot.*, 1902, 270.

[27] Gaedecke, *Phot. Woch.*, 1906, 41. Lumiere and Seyewetz, *Brit. J. Phot.*, 55 (1908), 417. Charriou, *Compt. rend.*, 117 (1923), 482. Amor, *Brit. J. Phot.*, 72 (1925), 18.

The simplest method of removing the surplus water is to wipe the surface (both surfaces of film) with absorbent cotton, or a viscose sponge, saturated with water. The film should be kept well moistened all the while in order that any adhering dirt or slime may be removed as well as the excess water.

A satisfactory squeegee for removing the surplus water from roll or strip film may be made from the blades of two automobile windshield wipers mounted side by side. Film squeegees for the same purpose are also available commercially.[28]

Drying Equipment.—Negative materials should be dried in a good circulation of dry, dust-free air and preferably at a temperature between 75° and 95° F. (35° C.). Glass plates are usually placed in a drying rack of the type shown in Fig. 179. Cut films may be hung from one corner using wooden or metal clips. Some cut film developing hangers are so designed that the negative may be dried in the hanger; usually this results in the loss of about ⅛ of an inch along each side from uneven drying. The hangers may be suspended from a line or placed in a drying rack as used for glass plates.

A drying cabinet provides the most satisfactory means of drying negatives in quantity. The size of the cabinet and its design will depend upon the amount, size and character of the negative material employed. The cabinet should be large enough to hold the maximum number of negatives which can come from the washing tanks in the time required for drying and allow ample space between the negatives to permit free circulation of air. A cabinet larger than absolutely necessary is undesirable as it is more difficult to maintain an adequate circulation of air in a large cabinet than in a small one. For the same reason a long narrow shape is better than a square one.

A constant supply of warm, dry air is necessary for rapid and uniform drying. With small cabinets a good method is to force heated air by a fan through the cabinet from the bottom and out at the top, electric heating units being placed between the fan and the top of the cabinet. If other sources of heat are used, the heating unit is best placed outside the cabinet to avoid danger of fire. For this reason, metal cabinets are preferable to those of combustible materials.

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[28] In large plants, particularly those devoted to motion picture processing, a pneumatic squeegee is often used. Crabtree and Ives, *Trans. Soc. Mot. Pict. Eng.*, **11**, No. 30 (1927), 270.

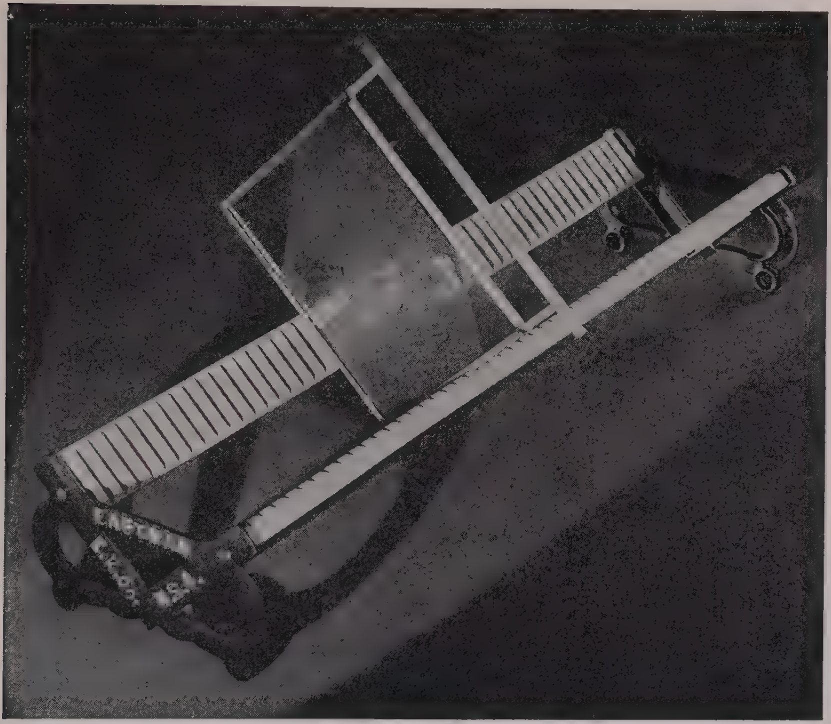

FIG. 179. Drying Rack for Glass Plates and Cut Films in Hangers. (Eastman)

The Time Required for Drying.—The time required in drying depends upon the following conditions:

1. *The amount of water absorbed by the gelatin.* This is proportional to the thickness of the swollen film; hence, the higher the degree of swelling the longer the time required in drying. For rapid drying undue swelling of the gelatin should be prevented by maintaining the temperature of the processing solutions and the water used for washing at 65° F. (18° C.) and by using a fixing bath with good hardening properties.

2. *The rate at which the air on the surface of the film is changed.* Air which remains in contact with the surface of the film soon becomes more or less saturated with water vapor and as the degree of satura-

tion increases, the rate of drying diminishes. It is important, therefore, to provide for rapid and continuous renewal of the air in contact with the film so that drying is not retarded. Small volumes of air at high velocity are more effective than large volumes at a low velocity.

3. *The relative humidity of the air.* The ratio between the amount of water in a sample of air and that required to completely saturate it at that temperature is termed the "relative humidity" of the air. The higher the relative humidity, that is, the more water the air contains, the less it can absorb; thus the relative humidity is an inverse measure of the drying power of the air.

The relative humidity is lowered as the temperature is raised, since the ability of air to absorb water increases with the temperature. The rate of drying, under given conditions, is inversely proportional to its relative humidity and increases with the temperature. The temperature of the drying air should not exceed 90° F. (32° C.) unless the film is specially hardened, or the gelatin is likely to melt.[29] The relative humidity of the air should, if possible, be held approximately at the volume which is in equilibrium with film having the desired moisture content; as film which has been too thoroughly desiccated is brittle. Best results are obtained with air having from 40 to 50 per cent relative humidity.

In general, the density and contrast of the image tend to increase with an increase in the relative humidity and temperature of the drying air. This is due in part to the increased rate of drying and in part to the softening of the gelatin which appears to result in the rearrangement of the grains of silver to produce a higher density.[30]

Uniform drying conditions are essential, therefore, if uniform negative quality is to be maintained.

It is essential that the rate of drying be the same for all parts of the negative, or variations in density are produced. These variations in density, commonly referred to as drying marks, are usually the result of drops of water adhering to the surface of the film during drying. Drops of water are less likely to form on film which has been properly hardened in an acid fixing and hardening bath, or if the surplus water is removed before drying.

Drying marks once formed may be removed by bleaching the image in potassium permanganate and redeveloping. See p. 354.

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[29] As for example, a chrome alum stop bath or an alkaline formalin hardening bath.

[30] White, *J. Soc. Mot. Pict. Eng.*, **29** (1932), 340.

Rapid Drying.—The drying of negatives from which prints are required immediately (press work, etc.) may be forced by the use of heated air, but only if the gelatin has been hardened sufficiently to prevent its melting. An alkaline formaldehyde hardening solution is recommended in such cases. Film negatives, however, cannot be dried at temperatures much above 100° (38° C.) or there is danger of the film base buckling.

Another method of drying negatives rapidly is through the use of liquids which evaporate more rapidly than water. Thus if a negative is placed for two or three minutes in denaturated alcohol, it may be dried rapidly in a current of air. Negatives treated with alcohol may be dried safely at a higher temperature than would be possible with a gelatin film charged with water.

The use of strong solutions of alcohol lead to opalescence of the image due to partial dehydration of the gelatin; however, with ordinary denatured alcohol, there is usually no trouble. The presence of traces of lime in the water may result in a whitish deposit which is not readily removed.

When drying with alcohol, care should be taken not to use the negative until it is thoroughly dry and not simply dry on the surface. Failure to do this may result in irrepairable damage to the negative.

Concentrated solutions of certain salts which are highly soluble in water as, for example, aluminum or sodium sulfate and potassium carbonate have the property of replacing water in gelatin and may be used for the rapid drying of negatives.[31] Thus if the wet negative is placed in a saturated solution of potassium carbonate for 4 or 5 minutes the gelatin is almost completely dehydrated and after blotting off the surplus solution and wiping the surface with a soft cloth, the negative is ready for printing.

This process affords a means of drying a negative temporarily so that prints may be made for immediate use; when the prints have been made, the negative should be washed in running water for 10 to 15 minutes and dried in the usual way.

[31] Lumiere and Seyewetz, *Brit. J. Phot.*, 59 (1912), 360.

CHAPTER XVI

DEFECTS IN NEGATIVES

Introduction.—In the pages which follow some of the more common defects in negatives are described together with an explanation of their cause and prevention. Considerations of space prevent the inclusion of all the possible difficulties arising from the improper handling of the camera. In the present chapter, those of most frequent occurrence are discussed as well as those difficulties which arise through the improper treatment of sensitive materials in processing. The chapter has been designed to be convenient for ready reference and consequently the headings have been made sufficiently descriptive of the defect to enable it to be readily identified.

Part of Image Is Out of Focus.—Error in focusing or insufficient depth of field. Using camera swings without a sufficiently small diaphragm.

Blurred Image.—Image not properly focused. Camera moved—image uniformly blurred; subject moved—part of image will be sharp.

Part of Image Cut Off.—View finder does not include the same field as the lens. This is due to bad adjustment but all ordinary view finders are adjusted for an object some distance from the camera and do not include the same field as the lens on nearby objects.

When reversible view finders are used, trouble frequently arises from using the vertical portion of the finder for a horizontal picture and vice versa.

Dark Circle in Center of Negative.—Shutter opened with the camera closed.

Tangle of Lines.—Pinhole in bellows. Less frequently in camera front.

Double Image.—Accidental double exposure. Small opening in front of camera. Failure to wind film after exposure (roll film). Shutter may not completely close.

Lack of Sharpness.—Plate or film holder does not register with ground glass. Ground glass reversed. Mirror out of register (Reflex). Marginal unsharpness—film not lying flat in focal plane.

Clear Spots.—Dust in camera. Brushing off films before loading in cut-film holder electrifies the base and causes dust to be attracted.

Fine Parallel Lines (on roll film.—Scratching of the emulsion from some sharp object in camera. Possibly grit. Pinhole in blind of focal-plane shutters.

Bright Objects Are Surrounded by a Vignetted Margin of Great Density.—Halation (see p. 248). Lens not clean.

Clear Band Across One Side of the Negative.—

1. Failing to completely withdraw slide of holder.
2. Cut-off by bellows.
3. Film tab of previous exposure not completely withdrawn (film pack).
4. Baseboard of camera in view (occurs only with wide-angle lenses when focused from the front).

Errors in Exposure and Development.—An underexposed negative is lacking in density and in shadow detail. If the degree of underexposure is slight, detail may be present in even the deepest shadows but does not have the contrast required for good printing quality. The contrast of the negative as a whole may be either low or high depending upon the subject and the degree of development.

An overexposed negative is dense and the contrast of the negative as a whole, and particularly the shadow portions, is less than that of a properly exposed negative. The lack of contrast is particularly noticeable if the time of development has been shortened to prevent the density from becoming too great.

Errors in exposure may be due to:

1. An error in estimating or measuring the brightness of the subject;
2. In making the proper allowance for the color of the subject or the nature of the light source;
3. In setting the diaphragm or shutter speed.

An underdeveloped negative is lacking in contrast and also in density, unless overexposed. Underdevelopment may be distinguished from underexposure by the presence, in case of the first, of shadow detail and its absence, in the second case.

Overdevelopment results in high contrast and density, particularly in the highlights. Overdevelopment may be distinguished from overexposure by the difference in contrast and the lower density of the shadow portions of the image. Errors in development may be due to:

1. The time of development,
2. The temperature,
3. Variation in the temperature during development,
4. The dilution of the developer,
5. The composition of the developer,
6. The rate of development of the sensitive material.

Fog.—Fog may be due (1) to exposure to light before or during development, (2) to the developer itself, (3) to impurities in the developer, and (4) to exposure of the sensitive material to air during development (aerial or oxidation fog).

Exposure to light before development may arise from a number of sources and may result in either local or general fogging of the image.

Local fogging may be due to:

1. Opening in bellows or front of camera admitting light.
2. Reflection from bright metal parts in camera.
3. Opening between the back of the camera and the film or plate holder, the film pack adapter or the roll holder.
4. Inserting the slide of a film or plate holder, or a film pack adapter by the corner, or twisting the paper tab of a film pack when withdrawing.

General fogging may be due to:

1. Exposing the film to an unsafe light when loading, or prior to development.
2. Exposure of the sensitive material to fumes of burning gas, gasoline, turpentine, ammonia, sodium sulfide, etc.
3. May also be due to an opening in the camera admitting light or to reflection of light from the folds of the bellows which have worn smooth through use.

Fog may be produced during development as a result of:

1. Excessive exposure of the film or plate to light.
2. The use of a safelight which is not suitable for that particular sensitive material.
3. A developing solution incorrectly compounded, containing too much alkali, too little restrainer, used without proper dilution or at a temperature above normal.
4. A developing solution contaminated with hypo or metallic salts such as those of tin, copper or zinc. Traces of these salts may

be due to old brass faucets or piping, to developing tanks and equipment of brass, to the use of solder in the construction of the processing equipment, or to mixing developers in galvanized vessels.

5. A developing solution containing sodium sulfide formed by the reduction of the sulfite by bacterial or fungous growths. This occurs ordinarily only in the deep tanks employed in photo finishing or in motion picture production where the developer is used without changing for several weeks. A developer which produces sulfide fog may be reconditioned by the addition of from 0.5 to 0.75 grams of lead acetate per liter. If the developer still fogs, it should be discarded.

   Sulfide fog may be prevented by keeping tanks and processing equipment clean and by sterilizing the tanks periodically with a solution of sodium hypochlorite followed by rinsing in water.
6. Excessive exposure of the sensitive material to air during development. The fog produced through oxidation of the developer when the developer-laden film is exposed to air during development is known as aerial or oxidation fog.[1] Under ordinary conditions, aerial fog occurs only with developers containing hydroquinone, but may be produced by other developing agents if contaminated with copper and tin salts. Aerial fog may be prevented by the addition of a small quantity of used developer or a desensitizer. One part of Pinakryptol green to 50,000 parts of developing solution is sufficient to prevent aerial fog under ordinary conditions.

An excess of sulfite will produce what is termed sulfite fog. Silver bromide is soluble in sodium sulfite, and the fog produced by an excess of sulfite is due to the reduction of the silver salt dissolved by the sulfite to metallic silver by the developer.[2] The amount of sulfite required to produce fog varies with different developers but is usually not less than 50 grains of sodium sulfite per liter. Where a large quantity of sulfite is required as in tank developers designed for continuous use or in fine-grain developers, the amount of potassium bromide should be increased, or the developer conditioned by the addition of a small quantity of used solution, to prevent sulfite fog.

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[1] Crabtree, *American Annual of Photography* (1920), p. 20.

[2] Mees and Piper, *Phot. Jl.*, **51**, 1911, 226; **52**, 1912, 221.

Developer or Oxidation Stain.—Stains due to the oxidation of the developer may arise from:

1. The use of an incorrectly prepared developer lacking sufficient sulfite to prevent excessive oxidation.
2. Developing at a temperature above normal thus favoring increased oxidation of the developer.
3. Exposing the sensitive material to air during development, before transferring to the fixing bath, or in the early stages of fixing.
4. The use of an old, oxidized developer.
5. The use of a plain fixing bath, or a partially exhausted acid fixing and hardening bath lacking sufficient acid to neutralize the alkali in the developer carried over on the sensitive material and prevent its oxidation.

The use of a stop bath is an almost certain preventative of all stains produced by oxidation after removing the film from the developer.

Developer stains may be removed as follows:

First harden the film by bathing for two or three minutes in an alkaline solution of formalin and wash for five minutes, otherwise the gelatin is apt to soften and frill during the subsequent treatment. Then bleach in:

	Avoirdupois	Metric
Stock Solution A		
Potassium permanganate	75 grains	5.3 grams
Water to make	32 ounces	1 liter
Stock Solution B		
Sodium chloride (table salt)	2½ ounces	75 grams
Sulfuric acid (pure concentrated)	½ ounce	16 cc.
Water to make	32 ounces	1 liter
Use equal parts of *A* and *B*.		

The solutions *A* and *B* keep well if kept separately, but not when mixed, and for this reason the bleaching-bath should be prepared as required.

The bleaching should be complete in about three or four minutes when there is usually left a general brown stain all over the film due to manganese oxide, and especially in those parts previously occupied by the image. It is best to remove this stain by first rinsing in water and then placing in a 1 per cent solution of sodium bisulfite. Wash for 3 or 4 minutes, and expose to a strong light (sunlight or arc light) until the white image turns purple. Then develop in a non-staining developer.

Local yellow stains on prints or negatives may be removed by superimposing a deep yellow filter over the negative and making a positive either by contact or in the camera and from this making a new negative. A panchromatic plate must of course be used and the yellow filter must be a contrast and not an orthochromatic filter.

Yellow Stains.—These consist of compounds of silver left in the film after fixing and washing. The presence of unfixed compounds in the film may be due to (*a*) the use of an old and exhausted fixing bath, (*b*) insufficient agitation of the film when transferred to the fixing bath, (*c*) fixing bath prevented from reaching film by another film, contact with side of tank, hanger, air bell, etc.

Yellowish White Opalescence.—This is due to the presence of finely divided, or colloidal, sulfur and arises from the use of a fixing bath (*a*) containing an excess of acid, or a deficiency of sodium sulfite, (*b*) too warm, or (*c*) the use of a plain potassium alum hardening bath after fixing.

The deposit of finely divided sulfur may be removed with a 10 per cent solution of sodium sulfite used at a temperature of 100 to 120 degrees F. (38° to 49° C.). The film must first be hardened in an alkaline formalin hardener.

Silver stain on the gelatin backing of film may be removed with iodine-cyanide reducer (p. 368) applied with a soft brush or wad of absorbent cotton on a stick.

Silver stains on the emulsion side may be removed (*a*) by photographing on panchromatic film through a strong yellow filter (not always successful) or by treatment with a 1 per cent solution of potassium cyanide (a deadly poison). The cyanide will dissolve the image in time, so the film should be removed as soon as any reduction becomes apparent and washed thoroughly before drying.

Silver Stain (Dichroic Fog).—This consists of finely divided silver and is reddish green by reflected light and pinkish by transmitted light, hence the name dichroic (two-colored) fog.

It is due to presence of a silver solvent in the developer, such as hypo, ammonia or sodium sulfide, or developers having an excess of sulfite or alkali, particularly when partially exhausted or when used at high temperature.

It may also be produced in an old fixing bath heavily loaded with silver and partly oxidized developer.

Silver stains can sometimes be removed by reduction in a ½ per cent solution of potassium permanganate until removed, followed by a 5 per cent solution of potassium metabisulfite to remove the brown oxide of manganese stain.

Sulfur Stains (Yellowish White).—Produced as a result of the precipitation of sulfur on the gelatin. Common sources are:

a. A fixing bath which contains too much acid or too little sulfite.
b. A fixing bath which is too warm.

Sulfur stains may be removed by bathing the negative in a 10 per cent solution of sodium sulfite at a temperature of 100° F. (38° C.). The emulsion should be hardened first in an alkaline solution of formalin.

Aluminum Sulfite Stains (Powdery White).—These are due to the use of an incorrectly compounded fixing bath containing insufficient, or impure, sulfite, an excess of acid, or one which is partially exhausted.

A frequent source where none of these factors is present is lack of agitation in the fixing bath.

Such stains may be removed by bathing the film in a 5 per cent solution of sodium carbonate and washing thoroughly. The gelatin should first be hardened in a solution of alkaline formalin.

Stains (Green).—A general green stain is sometimes produced when a hardening bath of chrome alum is used between developing and fixing, particularly if the concentration is too high or the temperature above 80° F. (27° C.). Ordinarily, the only effect is to increase the time of exposure in printing. Usually, the stain can be removed by immersing the negative for a few minutes in a 5 per cent solution of potassium citrate or potassium hydroxide. This treatment should be preceded by an alkaline formalin hardening solution.

Air Bells.—These are small circular transparent spots produced by air bubbles adhering to the emulsion surface and preventing development.

Circular, transparent spots with diffuse edges are produced when the bubble grows smaller as development proceeds.

Spots with a center of lesser density are produced when the airbell breaks or is dislodged.

Spots with unfixed silver halide are due to air bells in fixing.

Clear spots with a dark ring are due to developer oxidation fog around the air bubble.

The presence of a trace of oil or grease is an infrequent cause of air bells. In this event, the negatives should first be immersed in a

2 per cent solution of sodium carbonate, followed by two or three minutes washing in running water before development.

Spots.—Spots having dark narrow outlines are often caused by drops of water remaining on the film during drying.

Hazy white spots appear occasionally on negatives which are dried rapidly at high temperatures particularly when the processing solutions have been warm.

Spots surrounded by grey halos appear at intervals on negatives as a result of drops of water adhering to the base side of the film. When the negative is dried at room temperature, such spots are usually just barely visible, but become more prominent when drying rapidly at a high temperature. Spots of this nature as well as others due to the presence of drops of water during drying may be prevented by the efficient removal of the water on the surfaces of the negative before drying,

Irregular spots, almost clear, are sometimes due to traces of oil or grease on the emulsion or in the developer.

Frilling.—The emulsion softens along the edges and shows a tendency to leave the support; is more likely to occur with double, or thickly coated materials. Caused by the solutions being too warm, a developing solution which is strongly alkaline, a fixing bath which is exhausted or does not harden properly, or processing solutions at different temperatures. There is no remedy.

Reversal.—Image appears partly negative partly positive. Caused by exposure to an unsafe light in development, or a momentary exposure to white light, after development has begun. Sometimes caused by presence of hypo in developer. In this case, the unexposed areas are clear. Reversal by exposure to an unsafe light fogs the unexposed areas.

Streaks on Negatives After Drying with Alcohol.—Impure or exhausted alcohol. Incomplete fixation; alcohol too strong.

Scaly Effects.—Noticeable chiefly in sky or other area of uniform density. Insufficient agitation of developer. A particular type may be due to absorption of water through storage in damp place or exposure to damp air.

Row of Spots Along One Side.—In tray development due to part of film being immersed in one direction and the remainder from another direction. When the two wet areas meet airbells are formed.

Black Spots with Dense Tails.—Undissolved developing agents or alkali.

Yellow or Reddish Patches on the Negative.—Incomplete fixation. Printing from a damp negative on print-out-paper.

Band of Lesser Density Along One Side.—Film not completely immersed in washing tank. Hypo-laden gelatin is reduced by exposure to air.

Dark Line, or Band, Where a Shadow Area Joins a Heavy Density.—Due to the use of a partly exhausted developer and lack of agitation. The developer, not being kept in motion, diffuses from the area where it has had little work to do and produces a higher density along the junction line. Occurs most often in tank development when using dilute developers. Frequently known as the " Mackie " line.

Brown Scum.—This occurs in tank development when solutions are used over a period of time and consists of developer oxidation products which form a scum on the surface of the solution which is picked up by the film when placed in the developing tank.

It may be prevented by skimming the surface of the solution before use with the edge of a piece of blotting paper or cheese cloth on a wooden or wire frame.

Scum marks on developed negatives may be *removed sometimes* with a 1 per cent solution of potassium cyanide.

Fine Black Marks.—These are due either to abrasion or to static discharges arising from friction.

Rough, Whitish Deposit on Negative.—This is due to chalk in the water used in preparing the developing and fixing solutions or in the wash water. It may be removed by placing the negative for several minutes in a very dilute solution ½ of one per cent hydrochloric acid or in ordinary vinegar, then washing and swabbing the surface thoroughly with a viscose sponge or absorbent cotton.

Traces of the Dye Backing Remain.—The dyes used in non-halation backings are usually discolored by the sulfite of the developer or the fixing bath. Should traces remain after fixing and washing, the negatives should be placed in a 5 per cent solution of sodium sulfite, or in a fresh acid fixing bath, for about five minutes and then washed for five to ten minutes before drying.

Reticulation.—A wrinkling of the gelatin producing a leathery appearance caused by strains produced in the gelatin when it is transferred from one solution to another at a much higher or lower temperature, or from a highly alkaline developer to a strong acid fixing bath. There is no remedy.

CHAPTER XVII

REDUCTION AND INTENSIFICATION OF THE NEGATIVE

Photographic Reduction.—The operations by which silver is removed from the photographic image constitute what is properly termed photographic reduction. Photographic reduction, however, is not a process of chemical reduction but of oxidation, and photographic reducers are substances capable of converting metallic silver into a silver compound which is soluble in water, in an acid, or other suitable solvent.

Photographic reducers may be classified as follows:

a. Subtractive: Reducers of this type remove an equal amount of silver from all densities (Fig. 180), thus increasing the density range of the negative. Subtractive reducers are used principally to improve overexposed negatives and positives or for removing fog.

b. Proportional: Reducers of this type remove from each density an amount of silver which is proportional to that of the original density (Fig. 180). Proportional reducers are useful chiefly as a means of reducing excessive density and contrast due to overdevelopment.

c. Super-proportional: With reducers of this type a greater proportionate amount of silver is removed from the higher densities than from the lower (Fig. 180). Super-proportional reducers are used principally for the reduction of overdeveloped negatives of contrasty subjects.

Ferricyanide-Hypo Reducer.—This well-known reducer is frequently termed Farmer's reducer from its originator Howard Farmer.[1] The chemical reaction is as follows:

$$(a)\quad 4Ag + 4K_3Fe(CN)_6 = Ag_4Fe(CN)_6 + 3K_4Fe(CN)_6,$$

$$(b)\quad 3Ag_4Fe(CN)_6 + 16Na_2S_2O_3 = 4Na_5Ag_3(S_2O_3)_4 + 3Na_4Fe(CN)_6.$$

The silver image is oxidized by the ferricyanide, forming insoluble silver ferrocyanide which is dissolved by the hypo.

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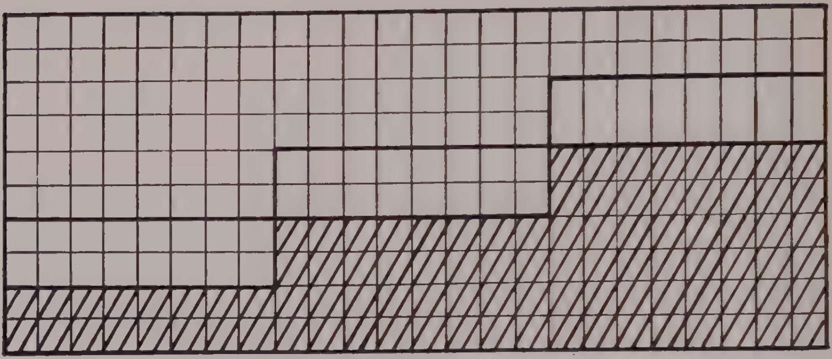
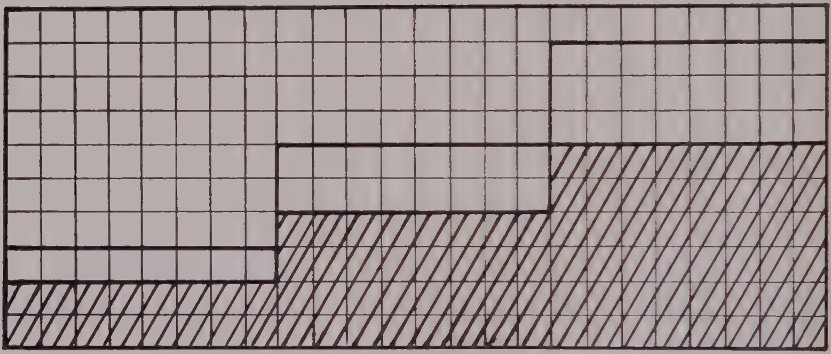
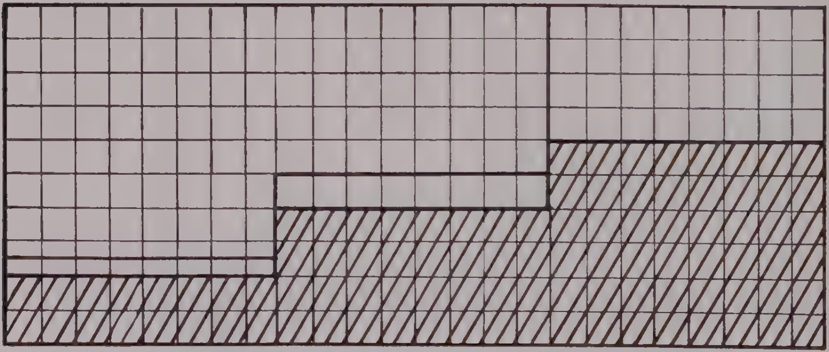
[1] *Yearbook of Photography* (1884), p. 59.



SUBTRACTIVE REDUCTION



PROPORTIONAL REDUCTION



SUPERPROPORTIONAL REDUCTION

FIG. 180. Types of Reducers.

The action is in the main subtractive but depends upon the nature of the silver image and the concentration of the reducing solution. With a relatively strong solution (1 per cent potassium ferricyanide and 10 per cent hypo) subtractive reduction is obtained with both negative and fine-grain positive film but with a dilute solution contrast is decreased and the action is more nearly proportional, particularly with negative materials.[2]

A mixture of potassium ferricyanide and hypo decomposes rapidly, hence the reducer is kept as two stock solutions:

Stock Solution A		
Potassium ferricyanide (Red Prussiate)	1¼ oz.	37.5 grams
Water	16 oz.	500.0 cc.
Stock Solution B		
Hypo	16 oz.	480.0 grams
Water	64 oz.	2.0 liters

If, after five minutes, further reduction is required, the negative should be transferred to a fresh solution to avoid stain. When the negative has been reduced sufficiently, wash thoroughly. To prevent excessive reduction from the continuing action of the reducer contained within the gelatin layer, the negative upon removal from the reducing solution should be flushed with an abundance of cold water.

Almost proportional reduction is obtained with ferricyanide and hypo by treating the negative in the ferricyanide solution first and subsequently in the hypo solution. The degree of reduction depends upon the quality of silver ferrocyanide formed in the first bath which in turn depends upon (1) the time of immersion and (2) the concentration of the solution.[3]

The following formula is satisfactory:

Solution A		
Potassium ferricyanide	¼ oz.	7.5 grams
Water to make	32 oz.	1.0 liter
Solution B		
Hypo	6¾ oz.	200.0 grams
Water to make	32 oz.	1.0 liter

Treat the negative in Solution *A* with uniform agitation for 1 to 4 minutes at 65–70° F. (18–21° C.), depending upon the degree of reduction desired. Then immerse in Solution *B* for 5 minutes and wash thoroughly. The process may be repeated if more reduction is desired. For the reduction of general fog, 1 part of Solution *A* should be diluted with 1 part of water.

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[2] Crabtree and Muehler, *J. Soc. Mot. Pict. Eng.*, 17 (1931), 1001.

[3] Crabtree and Muehler, *J. Soc. Mot. Pict. Eng.*, 17 (1931), 1001.

Ferricyanide and Ammonium Sulfocyanide.—This single solution reducer, which is due to Haddon[4] is of the subtractive type, but unlike ferricyanide-hypo, is stable.

The chemical reactions are as follows:

$$(a)\ 4\mathrm{Ag} + 4\mathrm{K_3Fe(CN)_6} = \mathrm{Ag_4Fe(CN)_6} + 3\mathrm{K_4Fe(CN)_6},$$

$$(b)\ \mathrm{Ag_4Fe(CN)_6} + (\mathrm{X}+4)\mathrm{NH_4CNS} = \mathrm{XNH_4CNS\cdot 4AgCNS} + \mathrm{(NH_4)_4Fe(CN)_6}.$$

The following formula is satisfactory:

Potassium ferricyanide	22 gr.	5 gm.
Ammonium sulfocyanide	44 gr.	10 gm.
Water to make	10 ozs.	1000 cc.

After reduction, wash well in running water. If a white deposit appears on the gelatin surface, dip the negative in hypo for a moment and wash well in running water.

Ferricyanide and Cyanide.—A mixture of ferricyanide and cyanide forms a stable reducer of the subtractive type but with the disadvantages of being highly poisonous and having a softening action on gelatin, thus rendering a preliminary hardening bath of formalin necessary.

The following formula is satisfactory:

Potassium ferricyanide	10.5 gr.	2.5 gm.
Sodium cyanide	10.5 gr.	2.5 gm.
Water to make	10 oz.	1000 cc.

Iodine-Cyanide.—A dilute solution of sodium or potassium cyanide and iodine forms a reducer of an intermediate character, being mainly subtractive but tending towards proportional reduction. It has the disadvantages (1) of being highly toxic and (2) unstable so that it must be prepared immediately before use.

The reaction is as follows:

$$2\mathrm{Ag} + \mathrm{I_2} + 4\mathrm{KCN} = 2\mathrm{KAg(CN)_2} + 2\mathrm{KI}.$$

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[4] *Brit. J. Phot.*, 39 (1892), 49, 60.

[5] The use of potassium cyanide and mercuric chloride has been suggested but offers no real advantages. Eder, *Handbuch*, 1883.

Potassium cyanide	22 gr.	5 gm.
Iodine (crystal)	4.5 gr.	1 gm.
Water to make	10 oz.	1000 cc.

Iodide-Hypo.—Equally as satisfactory and less poisonous is the following in which cyanide is replaced by hypo.

Potassium iodide	75 gr.	10 g.
Hypo	4 oz.	250 g.
Water to make	16 oz.	1000 cc.

This is non-staining, keeps well, and acts slowly and gradually.

Copper Reducer.—A reducer of the subtractive type which keeps well even after use may be prepared from cupric sulfate and hypo.[6]

Cupric sulfate	½ oz.	30 gm.
Sodium chloride	½ oz.	30 gm.
Water to make	12½ oz.	780 cc.

Dissolve and add ammonia until the precipitate first formed is redissolved. The solution is a deep blue.

For use, add an equal quantity of

Hypo	2½ oz.	360 gm.
Water to make	12½ oz.	780 cc.

If the action is too rapid, dilute with an equal quantity of water. Any bluish color remaining in the gelatin after reduction may be removed with a 0.02 per cent solution of sulfuric acid.

Permanganate Reducers.—The permanganates are strong oxidizing substances and if an acid solution of potassium permanganate is applied to a negative the silver is oxidized, forming silver sulfate which is soluble in water.

$$10Ag + 2KMnO_4 + 8H_2SO_4 = 5Ag_2SO_4 + 2MnSO_4 + 8H_2O.$$

The following is a suitable formula:

I.	Potassium permanganate	24 gr.	50 gm.
	Water to make	1 oz.	1000 cc.
II.	Sulfuric acid, C.P.	24 min.	50 cc.
	Water to make	1 oz.	1000 cc.

For use take 1 part of *A*, 2 parts of *B*, and 64 parts of water. When sufficiently reduced, immerse in plain hypo solution, fresh acid fixing bath, or 5 per cent solution of sodium bisulfite to remove the brown stain, after which wash well.

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[6] Smith, *Brit. J. Phot.*, **63** (1916), 574.

The formula as given acts as a subtractive reducer. Solutions containing less acid result in more nearly proportional reduction.[7]

Belitzski's Reducer.—This reducer consists of ferric chloride and hypo. Silver chloride and ferrous chloride are formed and the former converted into soluble salts by the hypo.

As a reducer, it is intermediate in character; the slope of the characteristic curve is lessened, *but* a greater proportion of silver is removed from the lower densities. It thus partakes of some of the characteristics of both subtractive and proportional reducers.

The following formula of Crabtree and Muehler[8] is much to be preferred to earlier ones:

Ferric chloride	365	gr.	25 gm.
Potassium citrate	2½	oz.	75 gm.
Sodium sulfite	1	oz.	30 gm.
Citric acid	290	gr.	20 gm.
Sodium thiosulfate	6¾	oz.	200 gm.
Water to make	32	oz.	1 liter

Proportional Reducers.—Attention has been called to the fact that approximately proportional reduction results from the use of ferricyanide-hypo in two solutions (p. 367) or permanganate in a neutral or very slightly acid condition (p. 369). Quinone or quinone sulfonates with sulfuric acid form proportional reducers, but the gelatin is stained.[9]

The use of mercuric nitrate with nitric acid has been stated to give proportional reduction, the gelatin is softened, however, and it is sometimes difficult to prevent reticulation.[10]

Proportional reduction may also be obtained with solutions of ferric salts rendered slightly acid by the addition of sulfuric acid.[11]

The reaction is probably as follows:

$$2Ag + Fe_2(SO_4)_3 \cdot (NH_4)_2SO_4 = Ag_2SO_4 + FeSO_4 + FeSO_4 \cdot (NH_4)_2SO_4.$$

The gelatin is stained if exposed to air during reduction, or if the negative has not been thoroughly fixed and washed. Prehardening in formalin is necessary to prevent undue softening of the gelatin.

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[7] Robin, *S. & I. P.*, **2** (1931), 24.

[8] *J. Soc. Mot. Pict. Eng.*, **17** (1931), 1001.

[9] Lumiere and Seyewetz, *Brit. J. Phot.*, **57** (1910), 625.

[10] Steigmann, *Phot. Ind.*, 1921, 697.

[11] Krauss, *Zeit. Wiss. Phot.*, **18** (1919), 192.

The following is a suitable formula:[12]

Ferric ammonium sulfate (ferric alum)	2	oz.	15 gm.
Sulfuric acid	1¼	fluid ozs.	10 cc.
Water to make	1	gal.	1 liter

Proportional reduction may be obtained through the combination of subtractive and superproportional reducers. A suitable combination consists of potassium permanganate and ammonium persulfate.[13]

The following is a satisfactory formula (Huse and Nietz):

Solution A

Potassium permanganate	38	gr.	0.25	gm.
Sulfuric acid (10%)	¼	oz.	15	cc.
Distilled water to make	35	oz.	1000	cc.

Solution B

Ammonium persulfate	¾	oz.	25	gm.
Distilled water to make	35	oz.	1000	cc.

For use take one part of A to three of B. Do not mix until immediately before use as the keeping qualities of the combined solutions is very poor. The time of reduction is from one to three minutes and after reduction the negative should be placed in a 1 per cent solution of potassium metabisulfite to remove the stain produced by the manganese salts precipitated in the gelatin.

Super-Proportional Reducers.—The number of reducers which act super proportionally is small; the alkaline persulfates alone are of practical utility although benzoquinone, Erdmann's salt $(CO_2(NH_3)_4 \cdot (NO_2)_8K_2)$, and potassium permanganate with ammonium sulfocyanide act in this manner under certain conditions.[14]

The persulfates are powerful oxidizers transforming the silver into silver sulfate which is soluble in the solution. The superproportional action of the persulfates is due probably to the catalytic effect of the silver ions formed during the reaction between the silver and the persulfate. Since the concentration of these ions increases more rapidly in the higher densities than in the lower the effect is to cause greater reduction of the higher densities.[15]

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[12] Crabtree and Muehler, *J. Soc. Mot. Pict. Eng.*, **17** (1931), 1001.

[13] Deck, *Brit. J. Phot.*, **63** (1916), 391. Huse and Nietz, *Brit. J. Phot.*, **63** (1916), 580.

[14] Benzoquinone: Lumiere, *Brit. J. Phot.*, **57** (1910), 625. Erdmann's salt: *Brit. J. Phot.*, **52** (1905), 437, 473. Potassium permanganate: Deck, *Brit. J. Phot.*, **63** (1916), 391. Huse and Nietz, Ibid., **63** (1916), 580.

As reducers the alkaline persulfates are somewhat erratic, sometimes refusing to act at all, and always acting more rapidly as reduction proceeds. To eliminate sources of uncertainty the following precautions should be observed:

1. Use pure ammonium or potassium persulfate. Some samples contain a trace of iron, the presence of which even to the extent of 1 part in a million is sufficient to affect the performance of the salt as a photographic reducer.[16]

2. *Use distilled water for preparing solutions of persulfate.* The presence of soluble chlorides, bromides, sulfates, and nitrates in the water used for preparing solutions of the persulfates is one of the most frequent causes of the erratic action of this salt as a reducer.

3. *Avoid the use of stock solutions of persulfate.*

4. *Immediately before use add a small amount of sulfuric acid.* The quantity added controls the rate of reduction. Usually 1–2 cc. per 1000 cc. (30 minims to each 32 oz.) is sufficient.

Persulfate	262 gr.	60 gm.
Sulfuric acid	15 minims	3 cc.
Water to make	10 oz.	1000 cc.

The action should be watched carefully as the rate increases with the degree of reduction and the negative may be reduced further than desired before the action can be stopped. Arrest the action by placing the negative in an acid fixing bath. Fix for about five minutes and wash.

A second method of securing super-proportional reduction has been published by W. J. Hickman. The negative is first bleached in an ordinary bleaching bath composed of potassium ferricyanide and potassium bromide as used for sulfide toning of prints. It is then washed for 3 to 4 minutes (not longer) and thoroughly re-developed in an ordinary metol-hydrochinon developer. After a brief rinse in water it is ready for reduction.[17]

For this purpose a weak solution of hypo (1 ounce to 20 ounces of water) is used. Reduction begins almost at once and should be followed carefully. When reduction has proceeded far enough the negative is removed and washed thoroughly in running water.

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[15] Higson, *Phot. Jl.*, 61 (1921), 237. Schuler, *Phot. Rund.*, 24 (1910), 113.

[16] Sheppard, *Brit. J. Phot.*, 65 (1918), 314.

[17] *Brit. J. Phot.*, 80 (Feb. 3, 1933), 59.

The theory of the process is that potassium ferricyanide is retained by the higher densities and when the negative is placed in hypo, differential reduction takes place from the formation of Farmer's reducer in those portions of the image in which the ferricyanide has been retained.

Super-Proportional Reduction through Bleaching and Redevelopment.—This process, known as "harmonization,"[18] consists in bleaching the image in an acid solution of potassium bichromate, then redeveloping in any non-staining developer until the desired density and contrast is obtained and fixing. The bleaching solution is the equivalent of the well-known chromium intensifier and the result of the process is to intensify the lower densities and reduce the higher since these are only partially developed, the undeveloped silver chloride being removed in the fixing bath.

Potassium bichromate	1	oz.	8.0 gm.
Hydrochloric acid (C.P.)	¾	fl. oz.	6.0 cc.
Potassium bromide	290	gr.	5.0 gm.
Water to make	1	gal.	1.0 liter

After bleaching, the negative is washed thoroughly to remove every trace of bichromate, then placed in the following redeveloper:

Elon	115 gr.	2.0 gm.
Sodium sulfite (desiccated)	1 oz. 145 gr.	10.0 gm.
Sodium carbonate (desiccated)	1 oz. 145 gr.	10.0 gm.
Water to make	1 gal.	1000 cc.

The image redevelops slowly and should be watched carefully. When the proper density and contrast have been obtained, rinse and fix in an acid fixing bath and wash.

Intensification.—Processes of increasing the density and contrast of the developed silver image are known as intensification. The increase in density is accomplished in one of three ways:

1. Through the deposition of additional silver on the image. (silver intensifiers.)
2. The addition of a metallic compound to the image. (Mercury, chromium, etc.)
3. Through the formation of a colored compound of silver, of another metal, or less frequently of dyes.

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[18] Eder, *Phot. Korr.*, **18** (1881), 111.

Intensification with Silver.—Intensification with silver is accomplished through the use of an acid solution of silver nitrate containing a reducing agent such as metol which results in the silver being precipitated preferentially on the silver deposits of the image. The amount of silver deposited is substantially in proportion to that of the image; hence the increase in density is proportional to the original density and the result is much the same as if the negative had been developed to a higher gamma. As the intensified image consists of silver, it should be as permanent as the original. Unlike many other methods intensification is complete in one solution; therefore, it is easily followed and controlled.

Many different formulas for intensifying with silver are to be found in the literature, but many are unstable and cannot be relied upon in practice. The following formula due to Crabtree and Muehler is an improvement over earlier formulas:

Solution 1			
Silver nitrate, crystals	2	oz.	60.0 gm.
Distilled water to make	32	oz.	1.0 liter
Solution 2			
Sodium sulfite, desiccated	2	oz.	60.0 gm.
Water to make	32	oz.	1.0 liter
Solution 3			
Sodium thiosulfate (hypo)	3½	oz.	105.0 gm.
Water to make	32	oz.	1.0 liter
Solution 4			
Sodium sulfite, desiccated	½	oz.	15.0 gm.
Elon	350	gr.	24.0 gm.
Water to make	96	oz.	3.0 liters

Prepare the intensifier solution for use as follows: Slowly add 1 part of solution No. 2 to 1 part of solution No. 1, shaking or stirring to obtain thorough mixing. The white precipitate which appears is then dissolved by the addition of 1 part of solution No. 3. Allow the resulting solution to stand a few minutes until clear. Then add, with stirring, 3 parts of solution No. 4. The intensifier is then ready for use and the film should be treated immediately. The degree of intensification obtained depends upon the time of treatment which should not exceed 25 minutes. After intensification, immerse the film for 2 minutes with agitation in a plain 30 per cent hypo solution. Then wash thoroughly.

The mixed intensifier solution is stable for approximately 30 minutes at 70° F. (21° C.).

Intensification with Chromium.—Intensification with chromium is effected by bleaching the image in a solution of potassium bichromate and hydrochloric acid or one of chromic acid and sodium chloride (or bromide) and then redeveloping in an ordinary developer.

The precise chemical reactions taking place are not definitely known but are probably as follows:

$2Ag + K_2Cr_2O_7 + 2HCl = 2AgCl +$ a reduction product of the bichromate, sometimes assumed to be CrO_2 or Cr_2Cl_2.[19]

When the bleached image is developed the silver chloride is reduced to metallic silver and the chromium compound remains, thus increasing the density.

The chromium intensifier has a number of advantages:

1. It is reliable.
2. The color of the image is changed but little.
3. The image has a high degree of permanency.
4. If the increase in density obtained with a single treatment is not sufficient, the operation may be repeated. The addition of density becomes less and less with each treatment, however, and generally little is gained from more than two treatments. The color of the image becomes more and more brownish with successive treatments.

A satisfactory formula for the bleaching solution is:

Potassium bichromate.................	3 oz.	90.0 gm.
Hydrochloric acid, C.P................	2 fl. oz.	64.0 cc.
Water to make.......................	32 oz.	1.0 liter

For use, take 1 part of stock solution to 10 parts of water.

The addition of 5 grams of potassium bromide to each liter (⅔ oz. per gallon) results in more rapid bleaching and greater intensification.

Decreasing the acid content of the bleacher results in a high degree of intensification but the time required for bleaching is increased. Practically little is gained from reducing the amount of acid in the above formula.

Incomplete bleaching results in relatively greater intensification of the lower densities than the higher.

After bleaching wash the negative in running water until every trace of the potassium bichromate has been eliminated. Then redevelop in a non-staining developer such as amidol, paraminophenol, metol, or metol-hydroquinone. Developers containing a high concentration of sodium sulfite should be avoided because of their solvent action on silver halide which may result in reduction of the lower densities. Developers containing a high concentration of sulfite also tend to produce brownish-colored images. A metol formula is suggested for redevelopment.

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[19] Lumiere and Seyewetz, *Brit. J. Phot.*, 66 (1919), 709. Piper and Carnegie, *Amat. Phot.*, 40 (1904), 336, 397, and Ibid., 41 (1905), 453, and *Brit. J. Phot.*, 53 (1906), 367. Crowther, *Brit. J. Phot.*, 66 (1919), 709.

Negatives intensified in chromium may be reduced in dilute solutions of hydrochloric (5 per cent) or sulfuric (2 per cent) acid which remove the addition product responsible for the increased density. Only film which has been hardened in formalin should be so treated or the gelatin may reticulate.

Intensification with Mercury.—In intensifying with mercury, the image is first bleached in mercuric chloride or bromide. The reaction which takes place is probably

$$Ag + HgCl_2 = AgCl \cdot HgCl.$$

In the redevelopment process which follows this silver mercurous chloride is reduced, producing a compound of silver and mercury or silver and a compound of silver and mercury, depending upon the nature of the redeveloper.

Bleach the negative completely in:

Potassium bromide....................	¾ oz.	22.5 gm.
Mercuric chloride.....................	¾ oz.	22.5 gm.
Water to make......................	32 oz.	1.0 liter

Wash for 5–10 minutes in running water. Redevelop in one of the following:

1. *A non-staining developer, such as amidol, paraminophenol or metol-hydroquinone.* Amidol is preferable since no alkali is required. Alkaline developers containing sulfite exert a solvent action which results in less than proportional reduction of the lower densities; these in fact, under certain conditions, may actually be reduced. Fine-grain developers, containing a large concentration of sodium sulfite, are not suitable. Ferrous sulfate is superior to any of the developers mentioned for this purpose but is now seldom used.[20]

2. *Ammonia.* This is frequently recommended but is not desirable because of its solvent action which may result in the lower densities being weakened rather than intensified.

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[20] Chapman Jones, *Phot. Jl.*, 50 (1910), 238.

3. *A 10 per cent solution of sodium sulfite.* This results in slight intensification but is not to be recommended (1) because of its solvent action on the image, (2) because the gain in density is slight and cannot be increased by repeating the process.

4. *A 2 per cent solution of sodium sulfide.* This is a satisfactory method of redeveloping if the gelatin has been hardened in alkaline formalin before bleaching. However, the color of the image is brownish and the density is not increased by repeating the process.

5. *A 10 per cent solution of sodium sulfantimoniate* (Schlippe's salt). This results in approximately proportional intensification and is one of the most satisfactory means of redeveloping. It is, however, little used at the present time.

6. *Silver-cyanide.* This forms what is known as Monckhoven's intensifier. It results in a high degree of intensification but the very low densities are reduced. This renders it well suited to the intensification of black and white line work, for which purpose it is principally used. The silver cyanide solution is:

Sodium or potassium cyanide	2 oz.	15 gm.
Silver nitrate	3 oz.	22.5 gm.
Water to make	1 gal.	1 liter

Note: The cyanides are deadly poisons and should be handled with extreme care.

Dissolve the cyanide and the silver nitrate separately and add the first to the second until a permanent precipitate is just produced. Allow the mixture to stand an hour or so and then filter.

Only the images which are redeveloped in ferrous oxalate or in sodium sulfide may be regarded as permanent.

Single Solution Mercury Intensifiers.—

Mercuric sulfocyanide	765 gr.	100 gm.
Ammonium sulfocyanide	460 gr.	60 gm.
Potassium sulfocyanide	615 gr.	80 gm.
Water to make	16 oz.	1000 cc.

For use dilute 1 part with 10 of water.

Another formula:[21]

Mercuric sulfocyanide	1540 gr.	200 gm.
Sodium chloride (salt)	1540 gr.	200 gm.
Water to make	16 oz.	1000 cc.

This also should be diluted with ten volumes of water for use.

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[21] Agfa, *D. R. P.*, 109, 860; 110, 357 of 1899.

After the negative has reached the desired density, it should be washed for 20–30 minutes in running water.

Mercuric-Iodide Intensifier.—This very convenient intensifier is prepared as follows:[22]

Mercuric iodide	90 gr.	2 gm.
Potassium iodide	90 gr.	2 gm.
Hypo	90 gr.	2 gm.
Water to make	10 oz.	100 cc.

The ingredients are dissolved together in a little water and the solution made up to the total given. Warm, but not hot, water may be used. The solution may be used repeatedly until exhausted. Intensification is progressive and may be stopped at will, when the density and contrast required have been reached. If only a small degree of intensification is required, the solution may be diluted with an equal quantity of water to make it work more slowly.

While the intensifier contains hypo, it is desirable that negatives be washed for 5–10 minutes before intensification. After intensification, wash in running water for 15–20 minutes. Negatives so intensified are not permanent. To render them completely stable, immerse in a 1 per cent solution of sodium sulfide until the image has been wholly changed—as viewed from the back—from gray to brown-black. The intensifying solution must be kept in the dark or in an amber glass or earthenware bottle.

Miscellaneous Methods of Intensification.—A simple method of obtaining a medium degree of intensification consists in converting the silver image into one of silver sulfide by bleaching and redeveloping in sodium sulfide as in toning prints. Only one degree of intensification is possible, as no increase in density is obtained by repeating the process.

The negative should be hardened in alkaline formalin before bleaching or the gelatin may be unduly softened in the alkaline sulfide bath.

Other toning processes such as those employing the ferrocyanides of uranium and copper may be used for the intensification of negatives. An extremely high degree of intensification is possible with uranium and the process is one of the best for faint images. The intensified image, however, is not permanent, as the silver ferrocyanide is readily decomposed into sodium sulfide. Since intensification with such processes is based upon the toning of the image, considerable experience is required to estimate the degree of intensification as the visual appearance of the image is not a direct measure of its printing density and contrast.

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[22] W. B. Shaw, *Brit. J. Phot.*, 80 (1933), 348.

Formulas for intensifying with uranium and copper will be found on pp. 447 and 446 respectively.

Intensification may be effected also by mordanting basic dyes to the image, using any of the well known mordants. See p. 448. A dye, or combination of dyes, which is free from color is desirable as the degree of intensification is more readily estimated from the appearance of the image.[23]

Sensitometry of Photographic Intensification.—A number of studies have been made (1) of the degree of intensification produced by the different methods and (2) the relation of the added density to the original density, but the most complete are those of Nietz and Huse.[24]

First, however, it is necessary to notice the effect of the color of the image upon the degree of intensification. Since positive materials in general are sensitive only to blue light, any change in the color of the image which increases its absorption of blue light is equivalent, from a photographic standpoint, to an increase in density, and thus the effective photographic density may be quite different from the visual density. The ratio of the visually measured density and the effective photographic density is termed the *color-coefficient*. The greater the difference in the density as measured visually and the effective photographic density, the higher the color-efficient.

The color coefficients for a number of processes are shown in the following table:[25]

Chromium (1 treatment) (D-72 redeveloper, 1 : 2)	M.P. Pan. Neg.	1.05
Chromium (2 treatments) (D-72 redeveloper, 1 : 2)	M.P. Pan. Neg.	1.19
Mercury (D-16 redeveloper)	M.P. Pan. Neg.	1.01
Silver	M.P. Pan. Neg.	1.00
Chromium (1 treatment) (D-72 redeveloper)	M.P. Positive	1.04
Mercury (Monckhoven's)	M.P. Positive	1.08
Mercury (D-16 redeveloper)	M.P. Positive	0.93
Silver	M.P. Positive	1.00

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[23] Ives, *Brit. J. Phot.*, **68** (1921), 186. Lumiere and Seyewetz, *Brit. J. Phot.*, **73** (1926), 147.

[24] Abney, *Phot. J.*, **44** (1897), 457. Janko, *B. J. Almanac*, 1898, 899. Bennett, *Phot. Jl.*, **53** (1913), 214. Clerc, *Brit. J. Phot.*, **59** (1912), 215. Nietz and Huse, *Phot. Jl.*, **58** (1918), 81; *Brit. J. Phot.*, **65** (1918), 179, 191.

[25] Crabtree and Muehler, *J. Soc. Mot. Pict. Eng.*, **18** (1931), 1001.

In Fig. 181 the percentage increase in density is plotted as the ordinate against the original densities as abscissae. A line parallel with the base would thus indicate proportional intensification. No intensifier reaches absolute perfection in this respect, although several approach it closely. The distance of the lines above the base indicate approximately the degree of intensification produced with the corresponding methods of intensification.

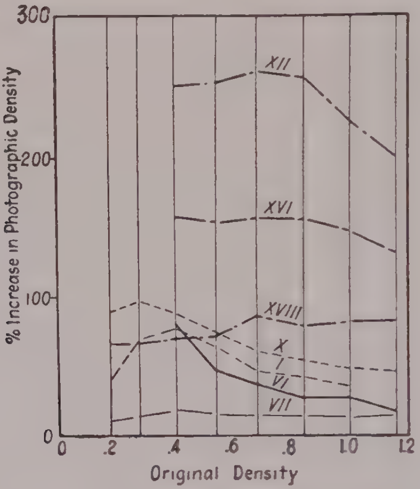

FIG. 181. Sensitometry of Photographic Intensification (Nietz and Huse). I. Mercuric chloride + ammonia. VI. Chromium + amidol. VII. Mercuric bromide + amidol. X. Mercuric iodide + paramidophenol. XII. Uranium. XVI. Mercuric iodide + Schlippe's Salt. XVIII. Cupric chloride + sodium stannite.

Local Intensification and Reduction.—Local reduction or intensification is of great assistance at times in bringing out certain details in the shadows or in reducing the density of an over-dense highlight. Conditions often arise in which local treatment of the negative or "dodging" of some sort in printing is unavoidable. There is often considerable reluctance towards the local manipulation of a negative which may be difficult to replace, and in many cases it is quite true that it is better to reach the desired result through dodges in printing than by work on the negative itself. Still, a little local reduction or intensification, carefully done, is the means of saving a great deal of time and waste of materials in printing.

If the negative to be reduced or intensified has been allowed to dry, it should be first soaked for fifteen to twenty minutes in water, while if the negative has been handled it may be well to add to the water a small amount of sodium carbonate to remove any grease present on the film.

The principal difficulty in local reduction or intensification with the usual methods is to confine the action of the reducer or intensifier to the area in question. With very small areas it is best to work on the dry film, but if the area is of any size this is likely to lead to streaks. On the wet film, difficulty is experienced in the diffusion of the solution over into adjoining areas where it is not wanted. On the whole, the best practice seems to lie in the use of a moist film, i.e., one from which the *surface* moisture has been removed by swabbing with absorbent cotton and the negative left to drain in the drying rack for several minutes.

For local intensification, the mercuric iodide method seems as satisfactory as anything else, since the growth of density can be watched and stopped when it has reached the proper point. For local reduction, Farmer's ferricyanide-hypo is satisfactory, the principal disadvantage being the likelihood of stains. Better in this respect is a reducer of potassium cyanide and potassium ferricyanide.[26]

To prepare this, equal parts of 2 per cent stock solutions of potassium cyanide and potassium ferricyanide are mixed and diluted as required to a strength which enables its action to be controlled.

For small areas, a water-color brush is the most useful tool for applying the reducer or intensifier. For somewhat larger areas a tuft of absorbent cotton saturated with the solution is less likely to result in uneven action. Unless rather strong solutions are in use, and generally that is not advisable, at least until the worker is experienced, the action can be stopped by holding the negative in a flowing stream under the tap.

Another method of local reduction consists in rubbing down the area, using an abrasive paste such as Eastman Reducing Paste or abrasive pencils such as the Eastman Reducing Pencil.

A most useful method of local intensification lies in the application of dyes to the area to be lightened. A yellow-orange dye suitable for this purpose is supplied by dealers as Coccine. The yellow, orange, and red of the more transparent water colors supplied for coloring lantern slides are also suitable. The well diluted colors are best applied to a moist film with a small brush. As soon as the area has been completely covered, remove the surplus color by blotting with clean blotting paper or absorbent cotton. If the degree of coloration does not appear to be sufficient, repeat the application. Successive application of diluted solutions, the surface color being blotted off each time, is much less likely to result in uneven application than the use of a strong color at the out-set. Some little experience is needed to estimate the printing effect of the color, but once this is gained, local manipulation with dyes is a very useful and convenient addition to methods of local control.

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[26] Lighton, *Brit. J. Phot.*, 73 (1926), 643.

The ordinary lithographic pencil, applied to the back of the negative, is often very helpful in holding back small areas which print too dark. The mark is easily removed.

CHAPTER XVIII

PREPARING THE NEGATIVE FOR PRINTING

Blocking Out.—The first essential for good work is a good desk. One which is too small is exceedingly trying to the temper and disastrous to good work. There should be a flat smooth surface sufficiently large to allow plenty of elbow room. It is best made of heavy glass and either flat or inclined at a very slight angle. The light beneath should be of good intensity and well diffused. Not all the light from the outside should be stopped out; it is important to be able to see the *surface* of the negative as well as to see through it.

A few good sable brushes of various sizes, a jar or tube of opaque, a drawing pen, a straight edge, preferably of metal, and a celluloid draftsman's curve complete the necessary accessories.

The negative should be clean and free of finger marks. If present, they should be removed with a tuft of cotton wet with benzine or carbon tetrachloride.

Where the subject contains a number of straight lines it is well to rule these with a draftsman's ruling pen, starting with the horizontal lines and ruling all of these first, then the vertical lines. Many of the curves may be ruled in by using the draftsman's curve; those which cannot, must be filled in freehand with a small brush. In using the brush, it is essential, if clear work is to be expected, that the hand should not be cramped. A free, rather flowing motion of the hand from left to right and away from the body, using the fingers underneath the brush as a sliding pivot, leads to smooth, clean work.

When the outline has been completely filled in, the next step is to widen the narrow line which now surrounds the subject. This is done with a somewhat larger brush; then any large areas are filled in with a still larger brush.

When dry, the negative should be given a thorough inspection. Small imperfections can be removed by using a slightly moistened brush, which must be cleaned after each stroke, but if much of such alteration is to be done, something is wrong with the blocking-out technique and the worker needs more practice.

Black Backgrounds.—At times, it is desirable to introduce a black background. There are several methods: The negative may be coated with collodion diluted with an equal part of alcohol and ether. Then the part of the negative to be removed is bleached with a solution of iodine, this part of the operation being analogous to blocking out with opaque. As soon as the area covered is seen to be clear and opalescent on the back, the plate is thoroughly washed under the tap and the negative immersed in hypo which removes the image. Finally, the plate is gone over with a piece of absorbent cotton, saturated with alcohol and ether to remove the collodion, washed and dried.

David Charles, writing in the *British Journal of Photography*, recommends bleaching out the background in a solution of potassium bichromate and hydrochloric acid as used for chromium intensification. The bleaching solution (rather stronger than for intensifying in the ordinary way) is applied with a brush, and when bleaching is complete, the negative (still held flat) is slipped into a 1 per cent solution of sodium carbonate which stops the action of the bleacher immediately. The negative is then washed three or four minutes and examined for rough edges where the background has not been completely removed. These edges are then touched up with the bleacher until the outline is clear and the negative placed again in the carbonate solution. Upon removal from the solution, it is washed one or two minutes, and placed in a plain hypo solution to remove any traces of the image which remain. Finally, it is washed and dried as usual. If any slight errors have been made in bleaching away portions of the image which are to remain, these can be restored before the negative is fixed by applying developer followed by fixing-out when they have attained the proper density.[1]

A second method of introducing a black background is to go over the image to be preserved with a water-proof varnish. When this is dry, immerse the entire negative in any clear working reducer until the background is reduced out. If the negative is thoroughly dry when immersed in the reducer, and the reducing solution is one which acts quickly, there will be no spreading of any consequence under the coated image.

Titles on Negatives.—The title or number may be lettered directly on the back side of a film negative, but unless one is able to letter well this should not be attempted, as poor lettering, is a draw-back to any print. Glass negatives must, of course, be lettered in reverse on the film side. So few are sufficiently experienced in this—even expert draftsmen—that it is seldom practical.

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[1] Charles, *Brit. J. Phot.*

Titles can be printed on negatives with rubber type, using an opaque ink. Sets of reversed type (photoscript) for printing on the emulsion side of the negative are obtainable commercially. Reversed type is not really necessary with film negatives, as the title may be printed on the back side.

Opaque paper letters of a suitable size, ready gummed (Dennison), may be used to number or letter negatives.

There are a number of ways of printing in the name of the studio without much additional trouble. One of the best of these is to letter, or have a printer set up, the desired lettering in type of suitable size and print on a thin transparent celluloid. Have the printer dust over the impression on the celluloid with lampblack before the ink dries. While having the work done, it is well to have several made up, as it is cheaper to have a number made at one time and those not needed immediately can be kept until required. The sheet of celluloid is placed between the negative and the paper when exposing the print so that the lettering appears in the position desired. The sharpness of the print will not be visibly affected as the celluloid is very thin.

Neat, clear-cut titles may be made by placing a sheet of Kodapak or cellophane a trifle larger than the negative between two sheets of black carbon paper with the waxed sides facing the cellophane and typing the desired inscription through a sheet of thin paper. The carbon paper being placed on both sides of the cellophane produces a copy with sufficient density to print white.

To make black letter titles on a white background, make a negative of the copy on process film and double print; print the negative first and then the title. To save film, only the title itself need be photographed, the smaller film being masked so as to protect the rest of the print when printing.

Retouching of Portrait Negatives.—The retouching of portrait negatives is frequently necessary for the removal of skin blemishes, and other imperfections, to improve the modeling and obtain a more pleasing effect. The amount of retouching required may be kept at a minimum by using color sensitive photographic materials, by lighting softly so as to avoid deep and sharply defined shadows, by using a soft-focus lens, diffusion disks, or other devices for softening the definition of the image, and by printing on a matte or rough paper.

The following materials are required:

Retouching desk
Retouching pencils (H, 2H, 3H and 3B)
Bottle of retouching medium
Etching knife
Absorbent cotton

Retouching desks may be purchased (Fig. 182) or built. A piece of opal glass should be fitted flush into a desk supported at an angle of about 40° and a 40 to 60 watt electric lamp placed below to illuminate the negative. If this arrangement is not convenient, the light reflected from a white cardboard may be used.

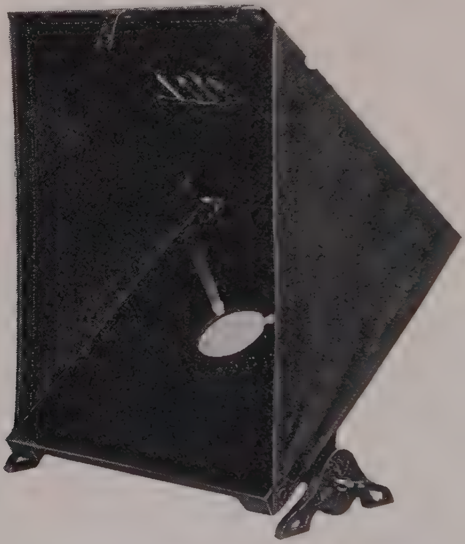

FIG. 182. Retouching Desk (Century)

Retouching pencils are supplied in various grades, or degrees of hardness, designated by the letters H, 2H, 3H and B, meaning black. For the beginner three grades, H, 2H and HB, are recommended. For retouching, the point of the pencil must be needle-sharp. This necessary condition is secured by sharpening the point on a sheet of fine emery paper.

Retouching medium may be purchased or made according to the following formula:

Pale gum resin	200 gr.	22.5 gm.
Gum dammar	90 gr.	10 gm.
Gum mastic	20 gr.	2.25 gm.
Oil of juniper	1 dram	6 cc.
Oil of turpentine	2–4 oz.	100–200 cc.

(*Whiting, Retouching*)

The gums are first powdered and then added to the oils; finally sufficient powdered asphaltum is added to give the mixture a dark amber color.

A drop or two of the retouching medium is placed on the part of the negative to be retouched and spread in a thin layer with a soft cloth or absorbent cotton, using a circular motion. Ridges or streaks, especially along the edges, are to be avoided.

The etching knife is used to reduce the density of small areas on the negative by scraping away some of the silver deposit. Success with the etching knife depends in a large measure upon its sharpness; it must be kept as sharp as a first quality razor or it will not be possible to shave away the silver deposit without producing scratches. Any etching required on a negative must be done before applying the retouching medium.

Retouching the Face.—It is essential before proceeding that the beginner have a clear idea of what he is attempting to do.

Retouching is a corrective process and it is not necessary to apply lead to the whole of the face but only where skin blemishes or other imperfections have resulted in a lower density than the surrounding portions. Beginning with the highlights, take one such spot and work on it until it disappears. Various strokes are used by retouchers in removing spots and suggesting skin texture. In the beginning, however, one should not pay so much attention to the stroke as to filling the spot with fine lines so that at a distance of ten or twelve inches it matches the density of the surrounding portions and is no longer perceptible. Do not attempt to fill up the spot solidly, or at once, but use a relatively hard pencil, such as 3H, and work slowly and patiently, filling each spot with a network of fine crosslines.

Begin in the highlights and work towards the shadows, using a more delicate touch in the shadows or thin portions of the negative than in the higher densities.

Modelling.—When the spots due to freckles and other skin blemishes have been removed, the beginner would do well to make a print to see the effect of his work. If it is unsatisfactory, he can remove the results of his labors by rubbing with a soft cloth containing retouching medium. It is probable that an examination of the negative will show certain areas to be blotchy, and gradations of tone which are abrupt or ragged. Perhaps there are some shadows which need to be lightened or highlights which must be blended with the surrounding areas. This may be undertaken next, using a fine, light stroke and a relatively hard lead. A knowledge of anatomy is a great asset at this stage. One must be careful to retain the character of the subject and avoid work which will show in the print. Retouching which attracts attention is often worse than none at all.

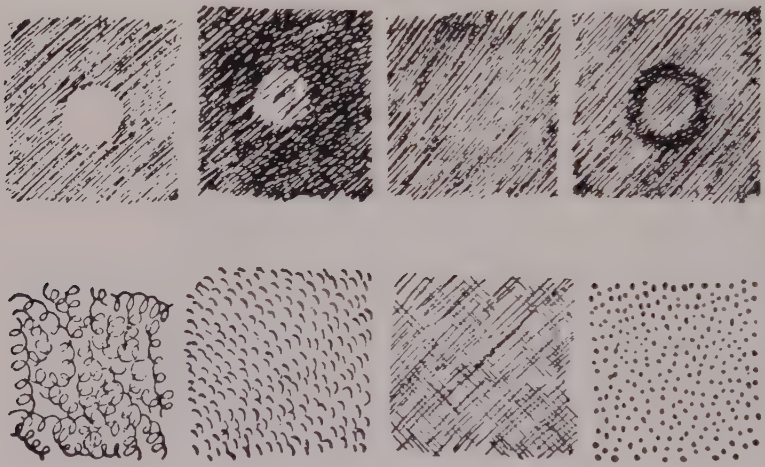

FIG. 183. Strokes Used in Portrait Negative Retouching (Cassell, Cyclopedia of Photography)

Retouching Individual Features.—Because of the method of lighting the subject, wrinkles and other character lines sometimes appear unduly prominent, and need to be subdued. They should not be removed entirely, especially in the case of men or old people. It is often well to idealize women's portraits, however, but not to the extent of destroying individuality.

Care must be taken to preserve the real character lines and merely soften unpleasant features. For instance, the transverse furrows in the forehead may be exaggerated, especially in the case of older people.

These can be toned down but the two highlights on the upper part of the forehead and the two above the eyes should be preserved.

When retouching the nose, begin on a line with a corner of the eye and work down the length of the bridge, blending softly down the side. If the shadow at the side of the nose is filled in too heavy, the nose will appear to blend into the cheek.

Work on the cheek should begin on the highest light, and extend back to the side and down about half way to the shadow between the neck and the chin. If carried on down, the chin may be made to appear too large. Sunken cheeks may have the shadows filled in somewhat.

But little work is needed on the chin and this should emphasize the highest light. Never work from the chin clear to the lips, or the shadow between the lips and chin may be lost.

Breaks or imperfections on the lips should be carefully filled, using light straight strokes.

Any lines at the corners of the mouth having a downward tendency may be softened somewhat.

The eye is the seat of expression and any attempt to modify it must be very carefully done. The catch light should ordinarily be on the iris about half way between the top and center of the eye. If it is too large or if it extends out over the pupil, a part may be removed with the etching knife as explained. It is sometimes well to strengthen the iris somewhat but this will make it print lighter in color. The "crow's-feet" and other lines at the corners of the eyes may be softened by partly filling up the shadows.

If enough lead will not adhere to properly build up certain parts, then the negative, if on portrait film, may be turned over and additional work done on the back.[2]

Varnishing.—A suitable negative varnish may be prepared as follows:

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[2] *Retouching and Improving Negatives,* Photo-Miniature No. 171, Tennant and Ward, Publishers, 70 Fifth Ave., New York City. *Retouching Not Difficult,* edited by F. R. Fraprie, American Photographic Publishing Co., 428 Newbury St., Boston, Mass. *Retouching and the Finishing of Photographs,* by J. Spencer Adamson, Frank V. Chambers Publishing Co., 636 South Franklin Square, Philadelphia, Pa. *The Art of Retouching Negatives and Finishing and Coloring Photographs,* by Robert Johnson, American Photographic Publishing Co., 428 Newbury St., Boston, Mass.

I	20% shellac solution	2 oz.	160 cc.
	Ammonia (0.880)	3 dr.	30 cc.
	Methylated spirit (methyl alcohol)	4 oz.	320 cc.
II	Japanese gold size	1 part	
	Benzole	2 parts	

This forms a rather slow drying varnish which, however, takes the pencil well.[8]

It is well to heat the negative slightly before varnishing to eliminate any moisture which may have been absorbed by the gelatin film. If either of the above or other cold varnish is used, the negative should be allowed to cool before varnishing. Film negatives are best treated by drawing them through the solution and then hanging up by one corner to dry. In varnishing glass plates the plate should be held by one corner in a horizontal position and the varnish poured on the center so as to form a pool. Allow this to spread and incline the plate slightly to each corner in succession, allowing any surplus to drain from the last corner into the bottle. If this is done carefully the varnish will not go beyond the edge of the plate. It is well to practice this technique on several waste negatives until it can be done without getting any of the varnish on the back. Allow plenty of time for the negative to dry. Varnishes differ in the amount of time required in drying; heat should not be used, however, to hasten drying.

Stripping Negatives.—To remove the emulsion from a *glass* negative for transfer to a new support, prepare the following solution:

Wood alcohol	25 parts
Water	1 part
Glycerine	1 part

A sheet of waxed paper slightly larger than the negative, some blotting paper, and a small quantity of hydrofluoric acid will be required.

Place the negative on the back of a tray or on a sheet of glass which is perfectly level. To each ounce (30 cc.) of the above solution, add 10 to 200 drops (1–10 cc.) of hydrofluoric acid and pour over the negative until the surface is covered. Spread the solution, if desired, with the edge of a piece of cardboard. After one or two minutes, try one corner of the film with the fingernail. If free, pull away the edges. When the emulsion appears to be free of the support, apply a sufficient amount of the alcohol-glycerine mixture to cover the emulsion and apply the sheet of waxed paper. Squeegee the paper to the emulsion, using a flat squeegee lightly, and remove the film from the glass by lifting one corner with a penknife and stripping the waxed paper from the glass.

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[8] *B. J. Almanac*, 1936, 353, 354.

The paper with its adhering emulsion is now placed on a glass plate which has been coated previously with a layer of soft gelatin, squeegeed lightly and the paper stripped, the point of a knife being used to hold the corner of the film on the glass.

The following solution should be used to remove the image from film negatives:

Caustic soda	100 grains	23 grams
Formaline	100 minims	21 cc.
Water to	10 oz.	1000 cc.

The negative is placed in this solution until the emulsion layer is loosened, stripped carefully and placed in:

Hydrochloric acid	25 minims	5 cc.
Glycerine	25 minims	5 cc.
Water to	1 oz.	100 cc.

It is then transferred to the new support.[4]

Working-in Backgrounds on the Negative.—Many portrait photographers are quite adept at working-in or altering backgrounds on the negative. The picture, in this case, is made with a plain background, the object being to have the background portion clear and free from any detail whatsoever. The negative is then attached to a sheet of ground glass, or to matt celluloid, and the design worked in with lamp black, lead, or charcoal, using a paper stump and a rubber eraser.[5]

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[4] These methods are taken from the *British Journal Photographic Almanac,* 1937.

[5] Photo Miniature No. 126, "Putting Backgrounds in Portrait Negatives," or Johnson's "The Art of Retouching Photographic Negatives."

CHAPTER XIX

PRINTING ON DEVELOPING-OUT-PAPERS

Developing Papers.—Developing papers for positive printing may be divided into three main divisions in accordance with the silver halide, or combination of halides, employed: (1) chloride, (2) bromide and (3) chloro-bromide.

Papers of the first class may be further divided into contact and projection papers, the difference being largely in sensitiveness. Papers of the type intended for photo-finishing or commercial photography develop quickly, producing black or bluish-black images, and are made in from four to six grades, or degrees of contrast; papers intended for portraiture develop more slowly, producing warm-black or brownish-black images and are supplied in a large number of different surfaces, but usually in not more than three degrees of contrast and frequently in only one.

Bromide papers are coated with an emulsion similar to that on films, except that it is much less sensitive, although bromide papers are usually much faster than chloride or chloro-bromide papers. Bromide papers develop slowly, producing a black image, and in this country are used almost exclusively for projection printing.

Chloro-bromide papers tend to produce warm-black, brown-black, and olive-black images and are widely used for portraiture and pictorial work when a warm-colored image is desired. In speed, papers of this type stand midway between the slower chloride papers intended for contact printing and the more rapid projection papers. They may be used therefore either for contact or projection printing, given light sources of the proper intensity.

In most cases a particular paper is obtainable in a wide variety of surfaces, the most common being (1) glossy (2) semi-matte or velvet

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BAINES—The Positive Processes in Photography. Chem. & Ind., **52** (1933), 443.

CHARRIOU AND VALETTE—Photographic Emulsions for Rapid Printing Papers. Chim. et Ind., **36** (1936), 888.

WANDELT—Modern Development Papers. Phot. Ind., **32** (1934), 1350; S.&I.P. (II), **6** (1935), 121.

(3) matte (4) rough and (5) rough lustre. Glossy papers dried on ferrotype plates so as to produce a high gloss are favored for reproduction. For pictorial work, the choice of any particular surface depends upon the subject matter of the picture and personal preference. In general, however, the semi-matte and matte surfaces are employed for small prints, the rougher surfaces being reserved for the larger sizes.

Characteristics of Photographic Papers.—The sensitometric methods employed in determining the characteristics of printing papers and the reproduction of tone with various printing media are, in general, the same as those used in the study of negative materials. In the case of papers, however, it is the density of the developed silver deposit by reflected light (the *reflection density*) and not the light transmitted (the *transmission density*) which is of importance. Measurements of the amount of light reflected from a density are made in specially designed densitometers in which the area to be measured is illuminated by diffuse light at an angle of approximately 45° to avoid specular reflection which would result in false values.[1]

The reflection density, unlike the transmission density, is not directly proportional to the mass of silver per unit of area but depends upon (1) the surface reflection, (2) the reflecting power of the paper stock, and (3) the mass of silver.

The reflection density may be expressed as

$$\log \frac{l}{R},$$

[1] Jones, Nutting and Mees, *Phot. Jl.*, **54** (1914), 342.

Jones, Nutting and Mees—Sensitometry of Photographic Papers. Phot. J., **54** (1914), 301; Brit. J. Phot., **62** (1915), 9, 22, 38.

Emmermann—Density Range of Papers. Atelier, **43** (1936), 116.

Emmermann—Paper Speeds and Contrast. Brit. J. Phot., **77** (1930), 181–183.

Jones—Contrast of Photographic Printing Paper. Correlation between Sensitometric Constants of Positive Materials and the Characteristics of the Optimal Positives and Negatives. J. Franklin Inst., **204** (1927), 41–89.

Jones—Contrast of Photographic Printing Paper. J. Franklin Inst., **202** (1926), 589–625; **203** (1927), 111–156.

Jones—Contrast of Photographic Printing Paper. J. Franklin Inst., **202** (1926), 177–204, 469–516.

Renwick—The Sensitometry of Photographic Papers. Phot. J., **55** (1915), 29.

where l is the intensity of light reflected from the paper base free of an image, and R the intensity of light reflected from the deposit after exposure and development.

When a developing paper is exposed in a suitable sensitometer, developed, and the reflection densities plotted against the logarithm of the exposure, the D-log E curve is found to be similar to that of negative materials. The principal observable difference in the curves of papers and negative materials is the comparatively low value of the maximum density. This is due to the fact that with papers we are dealing with reflected light and there are three surfaces from which the light is reflected: (1) the gelatin, (2) the silver deposit, and (3) the paper base beneath the silver deposit. The maximum density, therefore, is limited by the amount of light reflected by the surface and is seldom greater than 1.5 to 1.8, even on glossy papers. On matte papers, it is much less, ranging from 1.1 to 1.5.

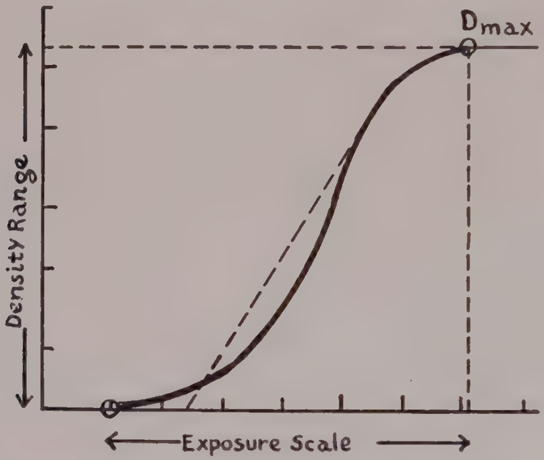

FIG. 184. Brightness Range Exposure Scale and Effective Gamma of a Printing Paper

The difference in the intensity of the light reflected from the paper base and the maximum density which the paper will produce constitutes what is termed the *brightness range* of the paper. Papers fixed without exposure to light reflect from 65 to 70 per cent of the incident light, while the maximum black varies with the character of the emulsion and the surface of the paper from 0.8 to 4 per cent. The brightness range of a typical matte paper is given by Mees[2] as 1 : 16, or in density units 0.0 to 1.2, and that of a glossy paper of good quality as 0.0 to 1.8 or even 2.0, the latter corresponding to a brightness range of 1 : 100. From this we may conclude that, in general, it is possible to reproduce in a print the range of brightnesses found in the average subject but, in the case of matte papers or subjects of high contrast, only by using the entire range of the paper.

With papers, as with negative materials, the straight-line portion of the characteristic curve represents the range in exposure over which correct (proportional) reproduction is obtained. This range is considerably less than the total scale of the paper; hence, except in the case of a subject of low contrast, correct reproduction must be sacrificed at both ends of the brightness scale.

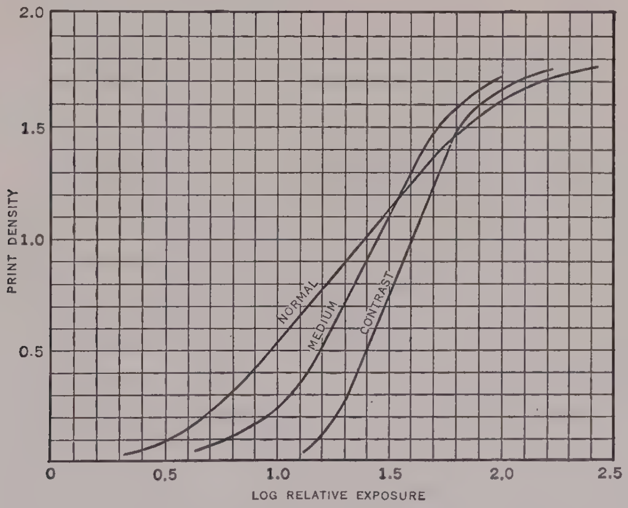

FIG. 185. *D*-log *E* Curves for Three Grades of a Paper

The contrast of a paper depends upon:

1. *The brightness range.* Other factors being constant, the greater the brightness range the higher the contrast.
2. *The slope of the straight-line portion, or more particularly the average gradient of the* D-*log* E *curve (gamma).*

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[2] Mees, *Phot. Jl.*, 64 (1924), 311; *Brit. J. Phot.*, 71 (1924), 445, 461.

With papers, the maximum gamma (gamma infinity) is reached at a comparatively early stage of development and shorter periods of development result in images of poor color and quality, so that in practice, papers are usually developed to their maximum gamma.

3. *The exposure scale,* that is, the range of exposures required to produce the complete range of brightnesses which the paper will yield.

This last factor varies from about 1 to 5 in the case of the so-called "vigorous" or "extra contrast" papers designed for amateur use to 1 : 16 or 1 : 32 in the case of the "soft or extra soft" grades, and from 1 : 50 to 1 : 60 in the case of bromide and chloro-bromide papers intended for professional use.

Papers having a short exposure scale are generally designated by some term implying contrast, for example, hard, vigorous, or contrast, because from a given negative they produce prints of greater contrast than similar papers having a longer exposure scale; such papers are designated as medium, normal, or as soft, or extra soft, according to the length of the exposure scale.

No necessary connection exists between the exposure scale of a paper and its quality. The quality of a paper is determined by (1) the maximum black—the higher the maximum black the greater the available brightness range—and (2) the length of the straight-line portion of a paper or, since this is frequently a relatively small part of the total curve, the length of the portion in which the gradient is sufficient to produce useful differences in brightness.

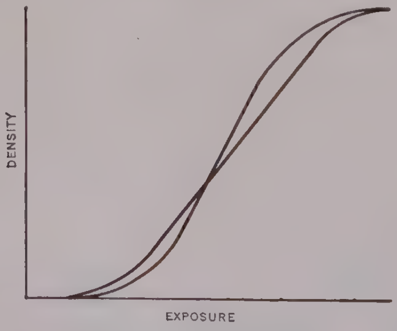

Fig. 186. Quality in Paper

Thus the two curves in Fig. 186 represent two papers, each having the same maximum density, the same brightness range, and the same exposure scale. In one of the curves, however, the straight-line portion is relatively short and at both ends of the scale the increase in density with increased exposure is very small, so that the brightness differences in the highlights and shadows are degraded. The second, on the other hand, the straight-line portion is much longer and only at the very extremities is the gradient too small to be useful. It is therefore, much the better paper from the standpoint of tone reproduction.

Adaptation of the Paper to the Negative.—It is evident that if the difference in the amount of light transmitted by the thinnest and the densest portions of the negative (the transmission range) is greater than the exposure scale of the paper, some of the density differences in the negative will not be represented by tone differences in the print. If the exposure for the thinnest portion of the negative is just sufficient to produce the maximum black which the paper will produce, the density differences of the negative at the other end of the scale are represented by white paper.

If the exposure is increased so as to reproduce the higher densities of the negative, several of the lower densities will be represented by the maximum black of the paper.

If the transmission range of the negative is less than the exposure scale of the paper, either the maximum black is not reached or the highlights are degraded, depending upon the exposure and the scale of tones is less than that required for a satisfactory reproduction of the brightness differences of the original.

It is evident then that, in general, the best results from the standpoint of tone reproduction are obtained when the exposure scale of the paper is approximately equal to the transmission range of the negative. Thus papers with a short exposure scale (contrast grades) are used for negatives of low contrast (narrow transmission range) and papers with a long exposure scale (soft grades) with negatives of high contrast (wide transmission range).

Then the exposure is regulated so that the tones which are of the greatest importance, that is, the tones within the most interesting part of the picture, as for example, the head in a portrait are placed either within the straight-line portion of the paper, D-log E curve, or as near it as is consistent with the best rendering of the remainder of the subject.

Exposing the Print.—When using a printing frame, the back of the frame is removed and the negative placed in the frame emulsion side up. (A sheet of clean glass must first be placed in the frame if a film negative is used.) The sensitive paper is then placed with its emulsion side facing the negative, the back of the printing frame replaced, and the springs clamped down.

While daylight may be used for the exposure, artificial light is preferable, owing to its greater uniformity. A convenient method of making the exposure is shown in Fig. 187. The distance between the light source and the printing frame should be kept constant and be sufficient to illuminate the negative uniformly.

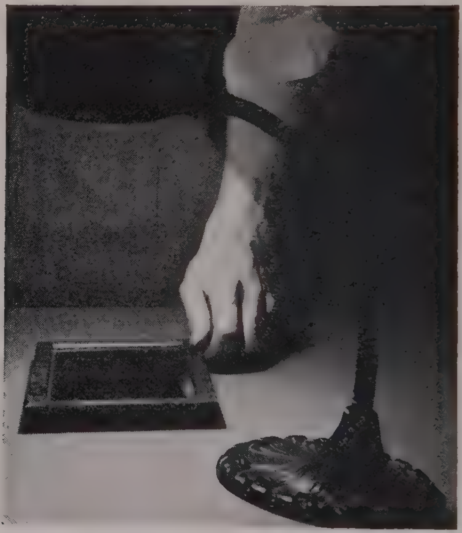

Fig. 187. Exposing Print with Gooseneck Reading Lamp

Printing Machines.—A printing machine is a more rapid and convenient method of exposing the print. A typical printing machine is shown in Fig. 188 (Eastman No. 2). It contains four 40-watt lamps which are switched on and off with the lowering and raising of the platen and a ruby pilot light which burns continuously. A ground glass to diffuse the light is placed directly beneath the printing bed and a masking device consisting of four adjustable metal strips is provided for convenient masking of negatives.

The Eastman Professional Printer (Fig. 189), designed for professional use, has a single concentrated light source carried in a movable fixture in which may be placed lamps ranging from 25 to 1000 watts. This movable fixture enables the intensity of the light to be

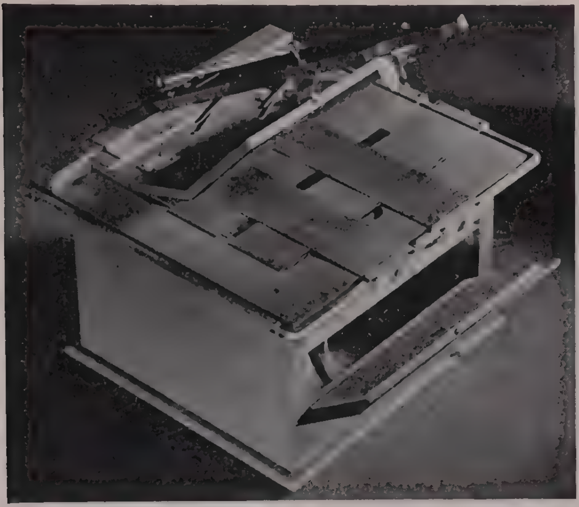

FIG. 188. Printing Machine (Eastman No. 2)

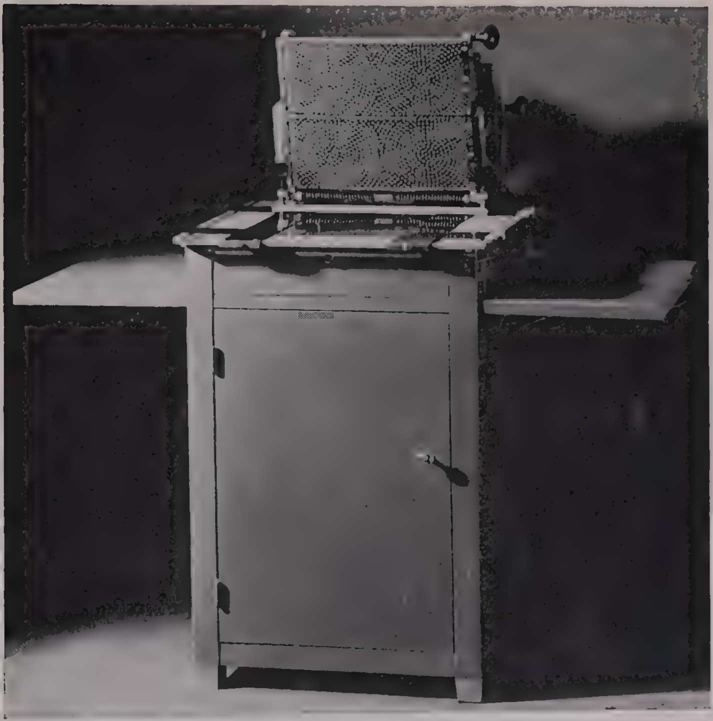

FIG. 189. Printing Machine (Eastman Professional)

adjusted to the speed of the paper, or the density of the negative, by simply moving the desired lamp into the printing position. A movable diffusion screen provides for controlled diffusion of the light from the single source.

The transparent rubber-studded printing platen results in positive contact, and yet facilitates control in printing, since shading may be followed through the transparent platen. Space is provided beneath the printing glass bed for the introduction of shading material.

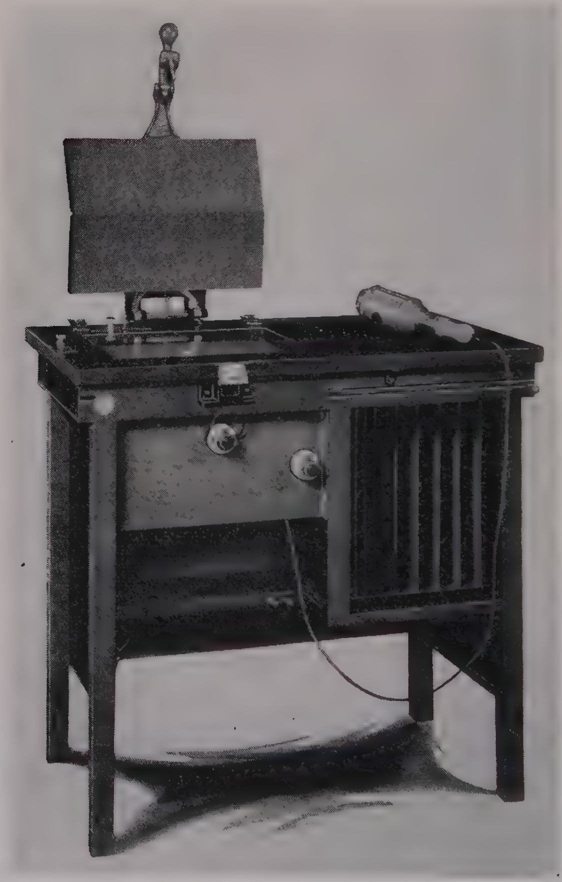

Fig. 190. Professional Printing Machine (Pako)

The Pako Professional printer is shown in Fig. 190. The unique feature of this machine is the provision made for local printing or "dodging." The printing head is hinged so that for local printing it may be brought to a vertical position as shown in Fig. 191 and local dense areas on the negative printed in with a small concentrating spotlight.

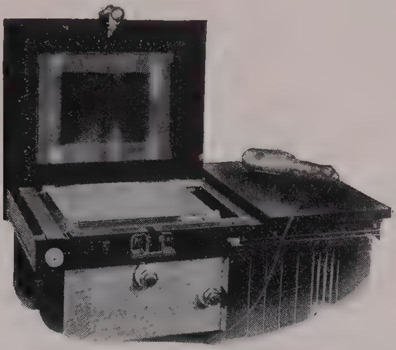

FIG. 191. Detail of Pako Professional Printer Showing Hand Spotlight Used for Local Printing

Special printing machines designed for photo finishing differ essentially from those used by portrait and commercial photographers in being designed for speed of operation. Usually, adjustable masking blades are provided so that only a moment is required to change when printing from different sized films. In many machines, the paper is held in place so that only two sides of the prints need be trimmed in order to obtain equal and uniform margins. In some cases, the bed of the printer is inclined so that after exposure the paper will slide off automatically into a tray. The printing area being small, the platen is usually made in one piece and paper clamps provided for holding the paper in place as the platen descends. In a number of printers, the platen is operated by a foot treadle so that the hands are left free for handling the negative and paper.

Usually each print is numbered on the back at the time of exposure by a numbering device which is fitted into the platen. This device is set to correspond with the order number on the envelope. The prints may then be assorted by the numbers on the back.

Recently, a number of printers making automatically timed exposures have been introduced. In these, any one of a number of fixed exposures, sufficient to meet the requirements of all average negatives, is made automatically when the proper key or lever is depressed. The exposures are controlled either by a shutter providing automatically timed exposures or the time of exposure is kept constant and the different exposures produced by changing the intensity of the light. This is accomplished by introducing the proper amount of resistance into the electric line from which the printing light operates. With such machines it is possible to make from 500 to 1000 average amateur prints per hour. While more expensive, automatic printers are more economical for the larger plants because of the lowered operating cost resulting from larger production and reduction in waste of time and material.

Improvement of the Print by Local Shading During the Exposure.—The improvement of the print through shading or otherwise altering the amount of exposure which a portion of the image receives and so controlling the values of the print is known as dodging.

The simplest method of dodging consists in shading, during the exposure, with an opaque card held in the hand and kept in motion to prevent a sharp edge. Shading may be utilized to hold back an area which prints too dark or to increase the exposure in the case of an area which prints too light. Small areas which print too light may be printed by cutting an opening of the proper size and shape in a piece of cardboard and using this to shade the rest of the negative so that it will not be over-exposed while the additional exposure is being given for the denser portion. A small area which prints too dark can be held back with a card of the proper size and shape attached to a piece of wire and kept in motion during the exposure so that the wire will not show.

It is very difficult to shade negatives in this way on many printing machines because the opaque platen of the printing machine prevents one from seeing what is being done. The principal objection to shading as a means of controlling local values, however, is that it is difficult to make a number of prints exactly alike.

If the negative is on glass the back is covered with ground-glass substitute and areas which are to be lightened are gone over on the back with a soft lead pencil. If the negative is on film, a sheet of clear glass is flown with ground glass substitute, the back of the film negative attached to the clear glass side, and the density of the areas to be lightened built up with a soft lead pencil. For larger areas crayon sauce, obtainable from artist supply stores may be applied with paper stumps or a small wad of cotton. Instead of crayon sauce many prefer a little ordinary blue water color applied with a brush. Unless the area is to be held back considerably, the blue color will probably be sufficient; yellow may be used sparingly for very thin areas. Areas which are to print darker may be improved by applying a little vaseline to the ground glass.

Great accuracy is not necessary since the thickness of the glass so diffuses work on the ground side that minor irregularities are smoothed out.

Another method of control which is suitable for areas not too small consists in placing a sheet of tissue or transolene (obtainable from photographic supply houses) an inch or so below the negative and applying water, oil colors, or opaque (much diluted) to the paper beneath those portions of the negative to be held back. Openings may be cut in the paper to accommodate those portions of the negative which need more exposure.

Thin wads of cotton placed on a sheet of glass an inch or so below the negative may be used to good advantage in some cases. A few printers use sand in a glass bottom tray in much the same manner.

Still another method (and a very convenient one) is to cut openings in onion-skin paper in such a way as either to hold back certain parts of the negative or to make them print darker, whichever is desired. The negative is placed on the printing machine and the area to be held back (or to be printed darker as the case may be) is outlined on a sheet of paper placed over it, using a wax pencil. The outline is made a trifle smaller than the area to be held back. Now take the point of a sharp knife and cut out the paper along the outline, making a saw-tooth edge. Place the cut-out paper mask on one of the clear glass shelves below the negative and center the negative over it so that the areas to be printed darker will be directly over the cut-out portions of the paper. The negative is now attached to the glass of the printer with Scotch tape and the print made. The sharpness of the outline may be controlled by placing it at different distances from the negative —the nearer it is to the negative, the sharper the shading.

Vignetting.—To produce a vignetted print (that is, one in which the image fades gradually into white paper) a subject with a white background is necessary.

To make a vignetted print, proceed as follows: Attach the negative to the glass of the printing machine (or printing frame) using two short pieces of cellulose tape. Place over the negative a sheet of clear glass and outline on this glass, using a wax or china-marking pencil, the portions which are to be vignetted. Remove the glass, and place over it a sheet of yellow-orange or "post office" paper and trace the outline on the paper. With the point of a knife tear out the inner portion leaving a jagged, saw-tooth edge. The rougher the edge and the longer the "teeth" of the saw, the better. Now place the cut-out mask on one of the sheets of glass several inches from the negative. The greater the distance between the mask and the negative, the softer will be the edge.

Some printers make vignetted prints by means of a glass-bottomed tray and sand. The black sand used by sign painters is best but ordinary fine-grain sand is satisfactory. To evenly distribute the sand the tray is shaken and then placed on one of the glass shelves directly beneath the negative. A soft brush is used to "shape up" the opening in the sand to produce the desired effect. By having the layer of sand thin along the edges, the light coming through the sand will produce a graded edge. The remainder of the layer should, of course, be sufficiently thick to prevent light from reaching the paper.

A vignetted effect may be produced on the negative with an air brush using a fine grade of lamp black or non-actinic color.

Developers and Development.—The development of prints is not essentially different from that of negative materials but certain factors which are relatively unimportant in negative development become of considerable consequence in the development of emulsions on paper. The factors of diffusion and absorption of the developing solution by the gelatin film become much less important, while development takes on more of the character of the so-called "physical" development, i.e., the reduction of the silver from a solution which interacts

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Bierman—Development of Chloro-Bromide Papers. Phot. J., **67** (1927), 444–445.

Bierman—The Control of Gradation in Bromide Printing by Development. Phot. J., **68** (1928), 456–461.

Formstecher—Two-Bath Development of Prints on Paper. Phot. Ind., **28** (1930), 551–552; S.&I.P. (II), **1** (1930), 253–254.

Jones—The Relationship between the Size of Particle and Color of Image. Phot. J., **51** (1911), 159, first paper; Phot. J., **57** (1917), 158, correction of first paper.

Schwarz—Substances Affording Development of Bluish-Toned Images on Gelatino-Silver Chloride Papers. S.&I.P. (II), **7** (1936), 113.

Seyewetz—Constitution of Substances Giving Bluish Images with Silver Chloride. Proc. Ninth Int. Congress of Phot. Paris. 1935. S.&I.P. (II), **6** (1935), 300.

Steigmann—Blue-Black Development. Camera (Luzern), **13** (1934), 100.

with the developer. This alteration in the character of development is not due, however, to the use of an accessory solution depositing silver, as in actual physical development, but to the solvent action of the sodium sulfite of the developer on the fine-grained silver bromide and silver chloride.

For bromide and chloride papers which are designed to produce prints with a black or bluish black color, metol-hydroquinone developers have almost completely displaced all others, although diaminophenol is preferred by some workers.

For warm-black and brown or olive-black colors on chloro-bromide papers, metol-hydroquinone developers heavily restrained with potassium bromide, chloro-quinol, or a combination of glycin, metol and hydroquinone are used. In any case, it is well to follow the formula recommended by the manufacturer.[3]

A factor of major importance in the development of prints is the color of the image. Excluding the effect of the paper base, the color of the image depends upon the dispersity of the silver deposit, i.e., the average size of the particles of metallic silver comprising the image. The smaller the average particle size, the warmer the color.[4]

With any given paper, the average size of the silver particles and the color of the image depend upon: (1) the composition of the developer and (2) the time of development. The purest black which the paper will yield is obtained when the solvent effect of the developer is at a minimum, i.e. when a relatively large proportion of alkali is employed with only sufficient restrainer to prevent fog and when the image is developed to finality, i.e. until the latent image is completely developed. The depth or darkness of the print, therefore, is not regulated by the time of development but by the exposure. Proper exposure may be defined as the exposure which, with development to finality in the developer recommended by the manufacturer for black or blue-black tones, results in a print of the proper depth or darkness.[5]

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[3] With a metol-hydroquinone developer it is possible to modify the contrast of the print to a certain extent by altering the proportions of the two developing agents. Increasing the proportion of hydroquinone tends to increase contrast while an increase in the proportion of metol reduces contrast. The effect is more marked with some papers than with others and is frequently negligible in the case of rapidly developing papers of the silver chloride type. Usually, the color and quality of the image suffer from any modification of the developer which is sufficient to result in an appreciable alteration in contrast, but this is sometimes of less importance than the ability to secure a print of acceptable gradation. See Beirmann, *Phot. Jl.*, **68** (1928), 456.

[4] Jones, *Phot. Jl.*, 51 (1911), 151.

Blue-Black Tones on Developing Papers.—The production of blue-black tones is facilitated with many papers, particularly those of the slow silver chloride type, by the addition to the developer of nitrobenzimidazol, benzotriazol, nitroimdazol, nitrosoquanidine, thiosemicarbazide, thiosemicarbazone, thioglycollic acid, 5-amidoquanide, quinone chloride, iodosobenzine, quinoline and potassium sulfocyanate. Typical examples are (1) 20–30 cc. of a 1 per cent solution of benzotriazol or 30–50 cc. of a cold saturated alcoholic solution of iodobenzine to each liter of a metol hydroquinone developer, (2) 1 part quioline to each 1000 parts of developer, and (3) 2 to 4 drams of a ½ per cent solution of potassium sulfocyanate to each 32 ounces of developer.[6]

Warm Tones by Direct Development.—To obtain warm tones on chloride or chloro-bromide papers, the alkali is reduced and the amount of bromide or other restrainer increased in order (1) to increase the solvent action of the developer and (2) to prevent the complete development of the exposed grains of silver halide before an image of satisfactory gradation and quality is obtained. The use of developing agents of low potential, such as chloroquinol and glycin, alone or in combination with metol and hydroquinone, is favorable towards the production of warm-colored images because of their greater sensitivity to the restraining effect of potassium bromide.

The color of the image with a given paper is dependent therefore on (1) the composition of the developer and (2) the time of development. Increasing the amount of restrainer tends to produce warmer colors due to the increased solvent action of the developer while reducing the time of development and increasing the exposure accordingly also tend to produce warmer tones. Hence, in producing warm tones on chloride and chloro-bromide papers, the time of development is determined by the color desired and the composition of the developer; such papers are not ordinarily developed to finality.

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[5] A very important factor in the production of good black tones is the use of a fresh developer. Chloride papers are very sensitive to soluble bromide, and, since the amount of bromide in the developer increases with every print developed, it is obvious that the developer must be renewed frequently if constantly good print quality is to be obtained. Contamination of the developer with hypo or other substances having a solvent effect on the silver halide are likewise to be avoided. Very small traces of hypo have a marked effect on the color of the image, changing it from a good black or blue-black to a degraded color.

[6] Steigmann, *Phot. Korr.*, **68** (1932), 75; *S. I. P.*, **7** (1936), 74. See also: Steigmann, *Camera* (Luzern), **13** (1934), 100; *S. I. P.*, **6** (1935), 299. Seyewetz, *S. I. P.*, **6** (1935), 300. Kieser, *Phot. Ind.*, **31** (1933), 997. Gossler, *Phot. Ind.* (1934), 476, 782; (1936), 1127. I. G. Farbenindustrie, *Phot. Ind.* (1935), 502. *Brit. J. Phot.* (August, 1936), **83**, 552.

Substances of this type have been placed upon the market abroad as Bellaton and Fegasol.

Fixation of Prints.—It has been conclusively proved that the time required for the fixing of prints is much less than for negative materials.[7] There are four reasons for this:

1. The smaller grain size of papers as compared with negative materials.
2. The thinner emulsion coating and lower concentration of silver halide.
3. The greater solubility of silver chloride as compared with silver bromide and silver iodide.
4. The porous nature of the support which allows free access of hypo from both sides.

The time required for fixing in a *fresh* fixing bath depends upon the paper, the concentration of hypo, and the composition of the fixing bath, but is seldom over one or two minutes. The customary ten to fifteen minutes is justified, however, when prints are fixed in quantities and in a used fixing bath.

Owing to the smaller quantity of silver halides per unit area, a given quantity of fixing bath will fix more prints than films. However, there is no ready means of determining from the prints themselves whether or not the bath is in good condition; hence it is important to be on guard against using the bath beyond the limits which result in thorough fixing. For an acid fixing and hardening bath with a hypo concentration of 25 per cent this limit is approximately 50 8 × 10 prints per gallon or an equivalent in other sizes.[8]

The use of two fixing baths is even more important than in fixing negative materials since (1) there is greater tendency to overwork the fixing bath in fixing prints, and (2) the proper fixing of prints depends upon keeping the prints in circulation during fixing to ensure access to hypo. The use of two fixing baths necessitates some handling of the prints in transferring from the first to the second bath and this in itself is an added guarantee of proper fixing.

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[7] Warwick, *American Photography,* **11** (1917), 639. Lumière and Seyewetz, *Brit. J. Phot.,* **71** (1924), 108.

[8] For methods of testing fixing baths, see p. 341.

See Weyde, *Brit. J. Phot.,* **82** (1935), 326.

Long fixation is harmful, particularly with a fresh fixing bath, as the relatively fine-grained image is slightly soluble in strong hypo, especially in an acid condition; thus prolonged fixing results in a reduction in the depth of the shadows and highlights which appear "eaten away." Longer fixing times by favoring the retention of the hypo by the paper base, necessitate longer washing.

Washing of Prints.—It is often assumed that prints are more quickly washed than negatives because of the porous nature of the base which will allow elimination to take place from both sides. This, however, is not true, and prints in reality require longer washing for an equal degree of elimination from hypo than do negatives. This appears to be due to the retention of small traces of hypo by the baryta base coating of the paper.[9]

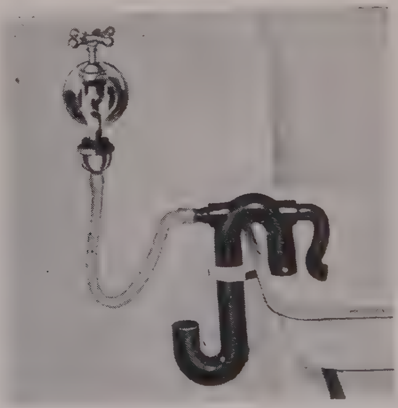

FIG. 192. Eastman Syphon Washer

While it is important that prints are kept exposed to fresh water and not allowed to collect in batches, agitation does not seem to have the same favorable influence in shortening the time of washing that it does in the case of negatives. A certain amount of soaking appears almost as effective as washing in running water. Hickman states that even under the most favorable conditions prints should be washed at least half an hour if on thin papers and an hour if double weight. Tests for the presence of hypo can, of course, be made either with permanganate or with mercuric bromide.[10]

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[9] Hickman and Spencer, *Phot. Jl.*, **64** (1924), 539.

[10] According to Weyde (*Brit. J. Phot.*, **82** (June 14, 1935), 376) the time required for washing may be greatly reduced by placing the prints in a 1 per cent

So far as efficiency is concerned, it is doubtful if any means of washing prints is superior to the use of a fairly large tray (16 × 20 or 20 × 24) fitted with an Eastman Automatic Tray Siphon (Fig. 192). The water entering the tray makes a complete circuit, keeps the prints on the move and well distributed, and is drawn off through the siphon; the water in the tray is thus changed every few minutes. Few washing devices provide so rapid changes of water.

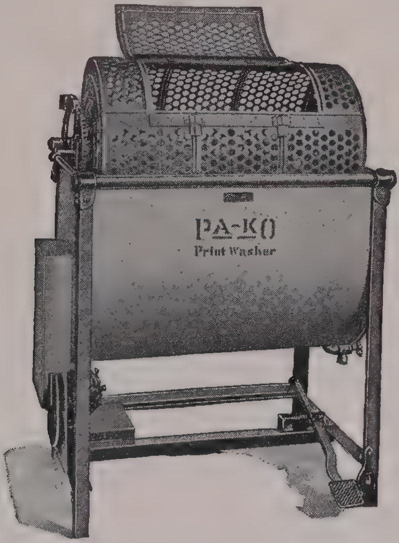

Fig. 193. Electrically Operated Print Washer (Pako)

For large batches of prints the cylinder cage type of washer (Fig. 193) in which the prints are placed in a cage which is revolved either by water power or an electric motor is more suitable, although it is not particularly efficient either from the standpoint of rapid water changes or keeping the prints well separated.

Drying Prints.—Prints on matte or semi-matte papers may be dried face up on blotters or on stretchers covered with cheese cloth or muslin. As prints left on the stretchers until bone dry will curl badly they are best removed when nearly dry and placed between blotters

solution of sodium carbonate for one minute after fixing and before washing. It is not advisable to use a stronger solution, nor to allow the prints to remain in the bath longer than one minute, or the whiteness of the paper may be affected, particularly if the print is dried by heat. Since a 1 per cent solution is rapidly neutralized by the fixing bath, a fresh bath should be prepared frequently.

and under pressure until dry. Never place wet prints between ordinary blotters to dry as they may stick.

A very satisfactory and convenient method of drying prints, except on glossy papers, is in a photo-blotter roll. This consists of a cloth-surfaced blotter, a plain blotter, and corrugated cardboard. The damp prints are laid face down on the cloth-surfaced blotter and covered with the plain blotter, then rolled up in the corrugated cardboard and fastened with a string or rubber band. The roll may be stood on end on the top of a radiator or hot-air register or laid on its side with one end facing an open window. Prints dried in such a roll come out smooth and with a slight outward curl.

Prints on glossy papers are usually dried on squeegee tins or on glossy print driers.

There are two kinds of squeegee tins: the black enameled ferrotype plates and the chromium plates. The latter are more durable, scratch less easily, and last longer. There is also less tendency for prints to stick to the plate particularly when dried by heat.

In either case the plates should be cleaned frequently with warm water to remove any particles of gelatin which may have been left on the plate when the prints were removed. It is not necessary to use a polishing solution each time the plate is used, but to prevent prints from sticking it is well to polish the plate every day or so. A good preparation for this purpose may be made by dissolving 10 grains of paraffin in one ounce of benzine. Any one of the many commercial preparations may be used instead if desired. Wet a tuft of cotton with this solution and go over the plate thoroughly; then polish off with a soft cloth such as canton flannel. There should be no visible trace of the solution left on the plate or the prints will have a greasy appearance.

When ready for use the plates should be placed on a drainboard or in the sink and sprayed with water to remove dust or lint: the more water on the plate the less likely air bells are to form beneath the print and the less danger of prints sticking to the plate.

Where heat is used in drying in conjunction with chromium squeegee plates, it is sometimes advisable to soak prints in a glycerin solution, 8 to 10 parts of water to 1 part of glycerin, for 5 minutes before placing them on the tins. This prevents prints from becoming brittle when dry and from cracking if run through a print straightener.

Prints should be taken directly from the wash water and, without draining, placed face down on the ferrotype plates being careful to avoid air-bells which will cause dull spots by preventing perfect contact. A slight pressure with the finger in the center of each print will prevent sliding.

It is not advisable to dry prints too rapidly or at a temperature above 150° F. as the gloss and color of the prints will be affected. Rapid drying may result in the formation of drying marks or circles on the prints, and a ground-glass or check effect on the surface of the plates. If a drying cabinet is used, it should provide for good circulation of air, but strong air currents striking the plates should be prevented by suitably placed baffle plates between the fan and the plates.

If prints adhere to the plate so that they cannot be removed, it may be due to one or more of the following causes:

1. The plate was not properly cleaned and polished.

2. The surface of the print was softened by prolonged washing, by washing in warm water or were insufficiently hardened because of an exhausted or improperly compounded fixing bath. Use a fresh acid fixing and hardening bath at a temperature not higher than 70° F. (21° C.).

3. The prints were dried at too high a temperature and without sufficient circulation of air. Avoid heat in drying and place the tins where there will be a good circulation of air.

Print Driers.—The most common form of print drier is that in which the prints are placed on a belt which passes over a heated drum revolved by a motor. There are several different types; some with a single belt and others with two. Some are adapted for semi-matte or

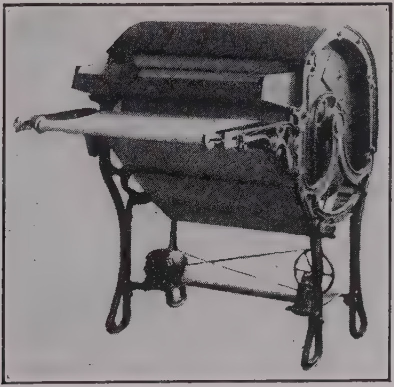

FIG. 194. Rotary Belt Dryer (Sickle)

matte prints, others for gloss prints. In the latter, the surface of the drum consists of polished chromium steel, and the prints are dried with the emulsion side in contact with the drum.

In another type of dryer, used exclusively for glossy prints, heavy flat chromium plates are attached at each end to two continuous steel roller chains being mounted in such a way that there is a belt of squeegee plates moving continuously from one end of a table to another. At one end, two wringer rolls squeegee the prints. In this way the plates move along from one end of the table to the other. The prints are dried by a gas or electric heating unit below. Such prints as are not dried on reaching the end of the table are carried around by the continuously moving plates to the under side of the table where, when dry, they leave the plates and are collected by a print pan from which they are readily removed.

A third type of drier is shown in Fig. 195. In this the prints are placed between linen faced blotters which, in turn, are placed between sheets of corrugated board. Warm air supplied by an electric heating unit is then blown through the openings in the corrugated boards by means of the electric fan shown at the left.

In the use of such driers, care should be taken to avoid undue heat. There is a great temptation, especially in rush periods, to increase the drying temperature and the speed of the drier but this should be avoided as not only are the color and brilliancy of the print affected by rapid drying, but the edges buckle. With glossy prints, rapid drying tends to produce a brittle print which cracks easily. If prints are well drained and freed of excess water before being placed on the belt, it is possible to use less heat and a slower speed.

Rush Prints.—Where time is an important consideration prints may be made from the negative as soon as it has been fixed by covering the emulsion surface with a sheet of thin celluloid, cellophane, or Kodapak. The negative will not be damaged if it has been thoroughly hardened in a properly compounded acid fixing and hardening bath, unless, of course, it is allowed to become quite warm.

The time required to dry prints may be reduced slightly by immersing the well-washed prints for about one minute, or until the paper assumes a transparent appearance, in methyl alcohol and then drying by heat. Less heat is required and the color of the image is not altered to the same extent as when drying is forced by the use of heat.

For still more rapid drying, the alcohol adhering to the surfaces of the print may be burned off. This, however, is not recommended except where speed is the primary consideration.

Prints for Reproduction.—The coarse half-tone screens (60–70 lines per inch) necessary for newspaper reproduction destroy fine detail and delicate gradations of tone. The picture, therefore, should be built up of distinct, clear-cut masses of light and shade. A light or medium tone background is better than a dark black one as black backgrounds are difficult to print on high speed newspaper presses.

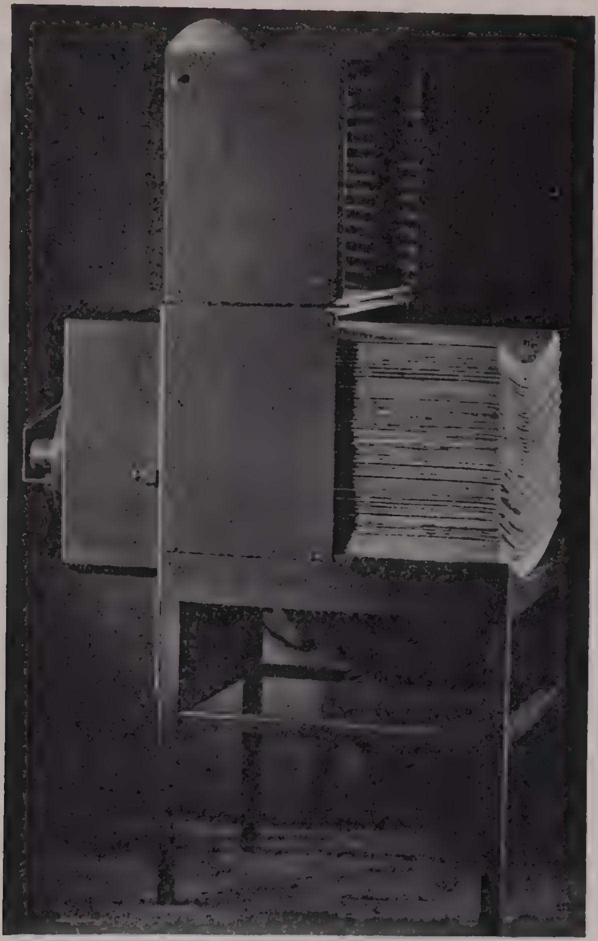

Fig. 195. Print Drier for Semi-matte and Matte Prints (Eastman Professional)

Prints for newspaper reproduction should be a trifle lighter than would be regarded as correct for other purposes, because of the tendency in newspaper printing for the half-tone dots to "fill in," which results in a reproduction darker than the original.

The print should be black or blue-black. Prints with a greenish or olive-black color are no longer desired by the photo-engraver. It should be on glossy paper, squeegeed, and have at least ½ inch margin. A print larger than the reproduction is desirable but if enlarging is resorted to, the print must be critically sharp and clear.

In printing upon coated papers finer line screens are used (80 to 145 lines per inch) and the detail and gradation of tone in the original can be more accurately reproduced than in newspaper work.

Prints for reproduction in publications using coated or calendared paper should have a full scale of gradation and not too much contrast. Contrast in the subject is desirable, but artificial contrast which is produced photographically through over-development of the negative or the use of a hard paper is to be avoided. A print with chalky highlights and dark shadows will in the ordinary course of events become still more contrasty when reproduced.

In rotogravure and photogravure, the best results are secured from photographs with clean, brilliant highlights and good rich blacks. Since both processes tend to increase contrast, the original should be rather softer than that for half-tone reproduction.

Reduction and Intensification of Prints.—Generally speaking, the action of the various reducers is the same as with negative materials.[11] The permanganate reducer acts nearly proportionally, while iodine cyanide is perhaps the best subtractive reducer because it is non-staining. For super-proportional reduction, persulphate alone appears suitable. In practically all cases it is necessary to use a diluted solution to keep the process under control.

For local reduction, iodine cyanide is especially suitable as it is non-staining and does not change the color of the image. The "waxy" appearance of the reduced area may be removed by washing the print for 5 to 10 minutes, fixing for 5 minutes and washing for 15 to 20 minutes.

Dry prints may be reduced with a spirit-soluble reducer composed of iodine and thiocarbamide in methyl alcohol.[12] In addition, there

[11] Jones and Fawkes, *Brit. J. Phot.*, **68** (1924), 275.

[12] Greenall, *Brit. J. Phot.*, **73** (1926), 73, 383.

STAUDE—Reducers for Paper Images. Phot. Rund., **73** (1936), 429.

is no continuing action to result in over-reduction and no tendency of the reducer to spread over into portions where it is not wanted. Two stock solutions should be prepared:

A—Iodine	20 gr.
Methyl alcohol	1 oz.
Shake now and then until dissolved	
B—Thiocarbamide	40 gr.
Water to	1 oz.

For use take equal parts of *A* and *B*. For areas requiring but little reduction, this may be diluted with an equal part of water.

The dry print is pinned down by the corners to a board and the reducer applied to the area to be reduced with a water color brush of appropriate size just wet with the solution. In the other hand must be a larger brush or tuft of absorbent cotton charged with the methyl alcohol which is applied to the print immediately not waiting to see if reduction has gone far enough. The excess alcohol is next blotted off and the operation again repeated if the first has not been sufficient. As soon as reduction is complete, dip the print in hypo (without previous washing) for a few minutes; then wash and dry as usual.

CHAPTER XX

PROJECTION PRINTING

Introduction.—Projection printing, as its name indicates, differs from contact printing in that the image of the negative is formed on the sensitive paper by projection. A lens interposed between the illuminated negative and the paper forms an image of the first on the second, the scale of this image depending upon the relation of the two conjugate distances, that is, the negative-lens distance and the lens-image distance. The greater the difference in the conjugate distances, or the total distance between negative and sensitive paper, the greater the scale or degree of enlargement. The scale, or degree, of enlargement is always expressed as the linear relation between the negative and the projected image; thus, from 4 × 5 to 8 × 10 is two times and not four times enlargement.

The apparatus employed for projection printing consists essentially of a negative illuminating unit, a camera, projecting lens, an easel or holder for the sensitive paper, and means of altering the distances between any of these without disturbing the parallelism of the negative and the sensitive paper or the relation of the optical axis of the lens to either of these two planes.

Projection Printing Equipment.—The introduction in 1921 of the Eastman Auto Focus Projection Printer may be said to have ushered in a new era in equipment for projection printing. It was the first apparatus for projection printing with automatic focusing and vertical design to come into general use. The principal differences in this and in earlier equipment were: first, and foremost, the automatic focusing device, whereby the focus is altered automatically as the size of the enlargement is changed; secondly, the fixed position of the light in relation to the negative for all degrees of enlargement; which avoids the necessity of adjusting the light for different sized enlargements—an advance made possible by the abandonment of condensing lenses and the use of high power tungsten lamps in a reflector; and third, the vertical arrangement.

Since the introduction of the Auto Focus Projection Printer, apparatus of this type has become quite general. While not as flexible as

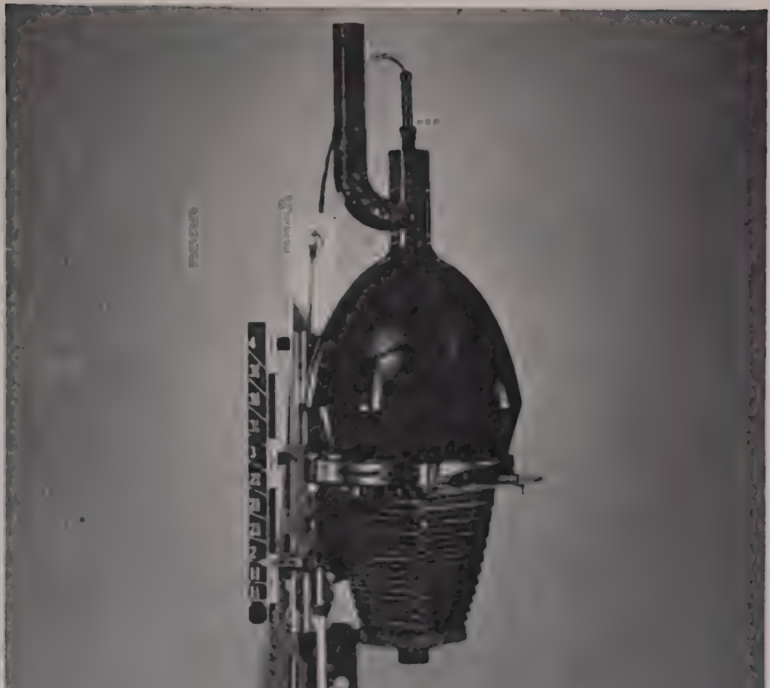

FIG. 196. Auto-focus Enlarger (Eastman)

the older instrument, the new more than makes up for this in convenience and rapidity of working.

Several projection printers have been designed in which the usual vertical arrangement is reversed, the illuminating unit and negative carrier being placed at the bottom, and the easel, in this case, usually of glass, on top. A platen which controls either the electric circuit or a shutter enables projected prints to be made in the same manner as contact prints in the usual printing machines.[1]

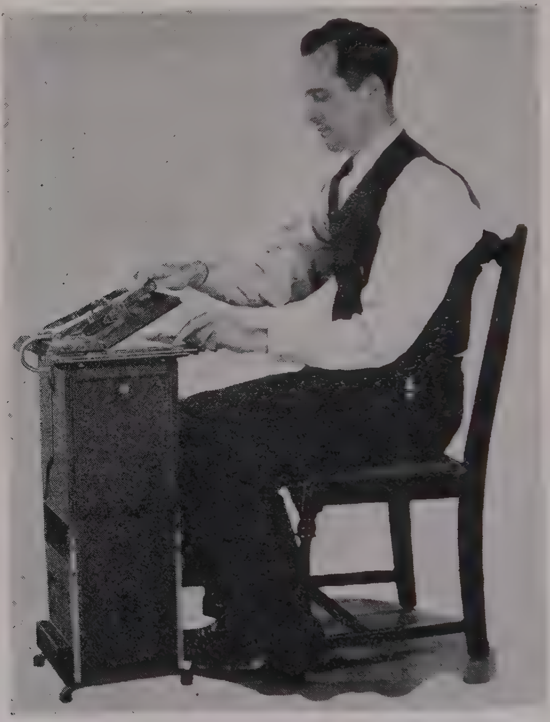

FIG. 197. Graflex Enlargor Printer

Light Sources and the Illumination of the Negative.—Electrical sources have practically displaced all others; incandescent lamps are

[1] As for example, the Enlargor printer of the Folmer Graflex Corporation (Rochester).

NORLING—Automatic Focusing Devices. Trans. Soc. Mot. Pict. Eng., **12** (1928), 1088–1092.

by far the most widely employed, although the electric arc and gaseous conductor sources of the mercury vapor type are still in use.

Incandescent lamps are usually used singly in reflectors and with ground or opal glass to secure uniform illumination. This reflector is usually of the parabolic type, with a satin finish aluminum surface.

In the case of a silvered mirror there is a bright spot in the center of the field which is the out-of-focus image of the light source. This is eliminated by sand blasting a spot in the center of the diffusing screen placed between the negative and the reflector. In the case of a reflector with a matt surface, the center spot is much more highly diffused and even illumination is obtained by means of a diffusing screen of sand blasted glass, heavily blasted in the center and gradually diminishing towards the margins or by using an opal glass bulb in conjunction with opal glass.

Condensing lenses are used when it is necessary to utilize as much of the incident light as possible in order to reduce the exposure as when making large scale projected prints or when using the slower papers. The condensing lens system employed consists of two plano-convex lenses, slightly greater in diameter than the diagonal of the largest negative and with their convex sides facing one another.

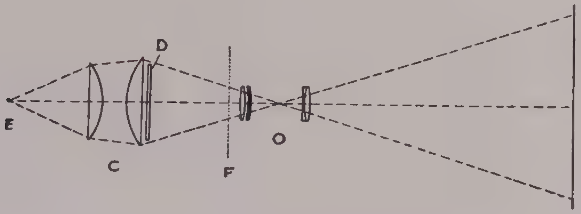

Fig. 198. The Function of the Condenser

The function of the condensing lenses is to collect the diverging rays of light and condense these on the negative, bringing the light rays to a focus in the projecting lens. Thus in Fig. 198 the light rays from the source *E* strike the first condenser and are refracted so that they enter the second condensing lens parallel to one another. In this second condensing lens further refraction takes place, the rays being converted into a converging cone the apex of which (or the focus) lies

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Cousins—Illuminating Factors in Enlarging. Brit. J. Phot., 64 (1917), 16.
Candy—Selection, Application and Manipulation of Condensing Lenses for Projection Printing. Amer. Phot., 17 (1923), 588.

at, or very near to, the principal nodal plane of the projecting lens, *O*. In this way the rays which in the absence of the condensing lenses would have continued on in straight lines and be lost are bent and made to pass through the lens, so that uniform illumination, together with a high intensity, is obtained.

From this it is evident that when condensing lenses are used without a diffusing medium, such as ground or opal glass, to secure the maximum intensity, together with uniform illumination of the negative, the light source must be located at such a point on the optical axis that its image, formed by the condensing lenses, is located at the principal nodal plane of the projecting lens. If we ignore the exact nodal planes, this means that the distances *AB* and *CD* (Fig. 199) are conjugate foci of the condenser, while the distances *ED* and *DF* are conjugate foci of the projecting lens. As the degree of enlargement is altered, the distances *ED* and *DF* will vary according to the laws of conjugate foci (See Chapter III). With every variation in *ED:DF* there will be a corresponding variation in *AB:CD*, so that in order to keep the image of the light source in its proper place at the principal nodal plane of the projecting lens the distance *AB* must be varied each time the degree of enlargement is altered.

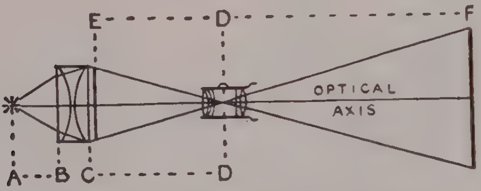

FIG. 199. Conjugate Foci in Enlarging

As condensing lenses afford the most efficient method of utilizing the light from a point source, they are usually employed with arc lamps in which the light source is approximately a point. The electric arc, however, is less convenient than incandescent lamps and is now seldom used except for large scale work where the greater intensity is an advantage.

Gaseous-conductor-tubes of the mercury vapor type are unlike the two preceding sources in that the area of the light source is much larger and very little heat is generated. Owing to the larger area of the light source the illumination is well diffused. The radiation emitted lies in a few bright spectrum lines and is weak visually but active photographically. Since the projected image is not bright, it is at times somewhat difficult to focus sharply or to exercise control through local shading during the exposure. In some cases, a number of relatively low-power, incandescent lamps are used with the mercury vapor illumination to produce a brighter image. An M-shaped tube is generally supplied; with this, a single sheet of ground glass is usually sufficient to produce a uniform, well-diffused source of illumination. The best results are obtained with negatives of greater contrast than would be suitable for other light sources and with comparatively clear shadow areas.

Negative Illumination and Print Quality.—Adequate diffusion of the illumination on the negative is a very important factor in the production of prints of good quality. The diffuseness of the illumination on the negative affects (1) the contrast of the print obtained under given conditions, (2) the graininess of the image, and (3) the sharpness with which scratches and similar imperfections as well as retouching and any handwork on the negative are brought out in the print.

Consider the negative and condenser system illustrated in Fig. 200. Pencils of light proceed from the source *S* in straight lines to the condenser where they are uniformly bent to new straight paths leading to the lens *L*. If, however, the negative is scratched some of the light will be deflected as shown in *B* of Fig. 200. The points on the negative where this deflection occurs are projected as dark areas. Suppose, now we substitute for the condenser, supplying approximately parallel rays, a window of completely diffused illumination as in *C* of Fig. 200. Each point on the negative is now illuminated by light from an indefinite number of directions; hence though the rays b and d do not reach the lens, *b′* and *d′* which, if the film were not scratched, would pass through in straight lines to be adsorbed in the bellows, are bent to pass through the lens. It is obvious, therefore, that the more the light is diffused and the larger the area of the window, the better chance there is of rendering surface inequalities invisible.[2]

Investigations by Tuttle indicate that the improvement as regards graininess and elimination of scratches and other surface effects is progressive with increasing diffusion up to a diffusion factor of ap-

[2] Hickman, "Enlargements from Cinema Negatives," *Brit. J. Phot.*, **74** (February 1927), 87.

Hickman—Display Enlargements from Single Frame Motion Pictures. Trans. Soc. Mot. Pict. Eng., **25** (1926), 49–57.

proximately 50 per cent beyond which the gain is very slight and the loss of light and the lower contrast of the image are of more consequence than the improvement in image quality. In general, as the scale of enlargement is increased the need for a high degree of diffusion in illumination increases.[3]

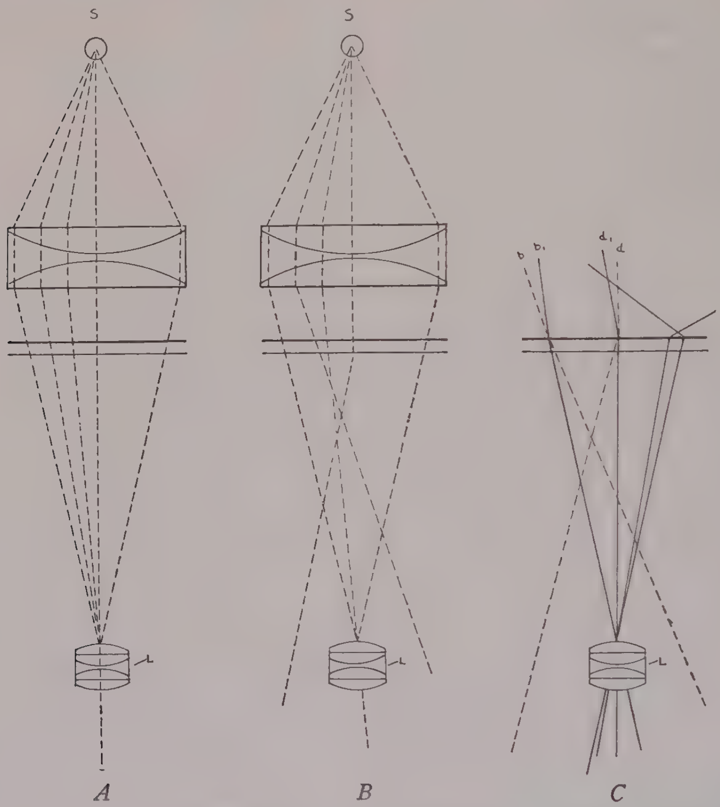

FIG. 200. Illustrating Illumination of the Negative in Projection Printing
A—Condensing lenses without diffusing medium and perfect negative
B—Condensing lenses without diffusing medium and scratched negative
C—Diffused illumination

Lenses for Projection Printing.—Lenses for projection printing should be well corrected for spherical and chromatic aberration and have an anastigmatic lens field. It is important, moreover, that these corrections be for a plane close to the lens. Generally lenses are corrected for an object distance which is relatively great as compared with the focal length of the lens. (Process lenses are an exception.) The lens used for projection printing, however, must be corrected for a short object distance, as the negative to lens distance and the lens to image distance are both short.

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[3] Tuttle, C., "Negative Illumination in Projection Printing," *J. Optical Society of America,* 1934 (October), 279.

Much of the better grade apparatus now on the market is fitted with lenses designed especially for projection, and projection anastigmats are available from several opticians but high grade anastigmatic lenses of medium aperture are usually adequate. In most cases, it is preferable to mount the lens so that the rays of light pass through it in the same direction as when used on a camera.

Papers for Projection Printing.—Papers for projection printing may be divided broadly into three types: (1) bromide paper, (2) rapid chloride or projection paper, and (3) chloro-bromide papers. The speed is generally in the order named although there are naturally wide variations in different papers. On the whole, the rapid chloride papers are several times slower than the average bromide paper and the chloro-bromide paper is slower still. All three types are made in a number of different grades, contrasts, and surfaces, to fit different negatives and different requirements. Properly developed, either bromide or rapid chloride papers will produce prints with a good rich black, but for tones suggesting a certain amount of warmth, the last mentioned are preferable. Chloro-bromide papers should be used where warm toned prints are desired.

So far as a choice between projection and bromide paper is concerned this depends most often upon the time of exposure. If the illumination, the negative, or the degree of enlargment is such that a comparatively long exposure is required with projection paper, then the use of a bromide paper is advisable on account of its higher speed. Relatively short exposures are desirable for a number of reasons: (1) time is saved and also electric current; (2) there is less danger of the negative becoming heated; (3) better gradation is secured with reasonably short than with long exposures. The failure of the reciprocity law is quite marked with printing papers, especially for low intensities, so that with weak illumination it is impossible to secure the same results by prolonging the exposure that would be obtained with a more intense illumination and a shorter exposure. A light source sufficiently intense for reasonably short exposures is necessary for good rich quality in projected prints.

Bromide papers and some projection papers require longer development than contact papers. The average time for development for the different papers is from 1½ to 2½ minutes. Full development is necessary if the best gradation is to be obtained. The time of development and the developer should be that recommended by the manufacturer of the paper. The use of a fresh developer with the proper amount of bromide is also an important factor in obtaining good tones and gradation.

The Negative for Enlarging.—Negatives for enlarging should be free from scratches, pinholes, and other physical defects. Very thin and soft negatives are not necessary for enlarging; this being a heritage from the days when light sources were much less intense than those in general use today. Negatives without undue density in the shadow portions are desirable, however, for the photographic negative acts as a scattering medium and the scatter of light in the shadow portions of the negative is a serious obstacle to a good, rich black. Negatives for projection printing should have rather less contrast than if intended for contact printing, since the tendency in enlarging is to increase contrast.[4]

The graininess of the negative is a very important factor. Where possible, therefore, fine-grain negative material and suitable processing techniques should be employed. In enlarging from small film negatives, the granularity of the image and defects due to minute scratches and abrasions of the film base can be reduced by immersing the film during exposure in a liquid of approximately the same refractive index as the film base. Suitable liquids for this purpose are glycerine or toluol. A small quantity of either of these is poured on a piece of clear glass and the negative laid down on the layer of liquid *so that no air bells are formed.* More glycerine or toluol is then poured on top of the negative and this covered with a sheet of glass; both sides of the film are thus covered with the liquid. In this condition the negative is inserted in the enlarger and the exposure made. After the enlargement has been made, the film is washed for 15 minutes and dried.[5]

The larger the degree of enlargement the smaller is the permissible circle of confusion in the negative. If it is assumed that the smallest permissible circle of confusion is 1/100 of an inch in the enlargement then the permissible circle of confusion in the negative will be 1/100 inch times the degree of enlargement. Thus, for a six times enlargement the permissible circle of confusion would be 1/600 of an inch. For pictorial work, it is, of course, possible in many cases to have a circle of confusion in the enlargement greater than 1/100 of an inch. In most commercial work it is doubtful if this limit may be safely exceeded, except in posters, photo-murals, and other prints normally viewed from a distance.

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[4] Callier, *Phot. Jl.,* 49 (1909), 200.

[5] Hickman, *Brit. J. Phot.,* 74 (1927), 87.

The greater the degree of enlargement then the greater the necessity for well-corrected camera lenses, accurate focus, and precision camera construction which will allow the definition of the lens to be utilized to the fullest advantage.

Adjusting the Light Source for Even Illumination.—Negatives on glass plates may be placed directly in the negative carrier. The usual practice is to place film negatives between two pieces of glass which must be free from flaws and perfectly clean. The special wet film holder supplied by the Eastman Kodak Company for the Autofocus enlarger and the Eastman Processing frame provide a means of

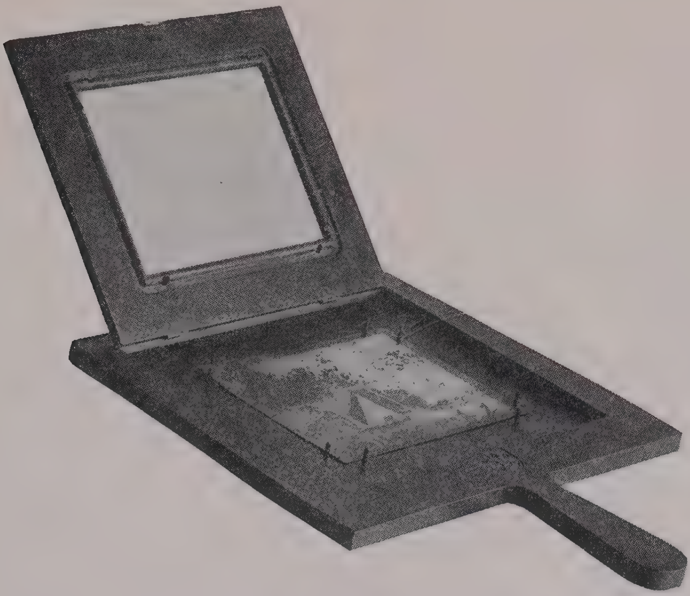

FIG. 201. Wet Film Negative Carrier for Enlarger (Eastman)

holding the negative in the carrier without necessitating the use of glass on either side. All of the light except that coming through the negative should be masked out. A number of projection printers have adjustable masks, or removable masks of metal; colored celluloid or opaque black paper may also be used.

When incandescent tungsten lamps are employed in reflectors, it is usually necessary to adjust the position of the lamp so as to uniformly illuminate the negative. Once this adjustment is made, it does not need to be altered when the degree of enlargement is changed.

With condensing lenses the position of the light must be altered when the scale of enlargement is changed. The negative should first be inserted on the carrier and focused roughly to size. The carrier should then be removed and the illuminated circle examined. If the field appears darker in the center, the light source is too far from the condensers and should be moved closer; if the outer margins are uniformly darker than the center, the light source is too close and should be moved away from the condensing lenses. Colored, or dark, crescent-shaped areas on one side are due to the light source being to one side of the optical axis.

When the light source has been adjusted to produce a uniformly illuminated field, the negative carrier is re-inserted, the image focused sharply, and the exposure made.

Focusing.—Focusing presents no difficulty with an automatic focusing projection printer; the lamp-house is simply moved up or down to regulate the size of the image which remains sharp in all positions.

With equipment focused by hand, there are a number of ways of obtaining sharp focus. The negative may be inserted in the carrier and the image focused roughly to ascertain the proper size. Then insert an old negative which has been scratched with a sharp pointed instrument in the carrier and focus sharply. In some projection printers, a focusing object, consisting of two cross lines on a glass plate, is fixed on the negative carrier. If projected prints are regularly made to certain degrees of enlargement, it is a very simple matter to attach to the instrument a scale which will avoid focusing.[6]

Microscopic devices for examining the projected image to determining the position of sharp focus are available commercially.

Exposing.—The exposure may be made (1) by turning the light on and off, or (2) by means of a cap or shutter. The first method is practical only in the case of incandescent electric lamps; because gaseous conductor tubes require several minutes in which to reach full intensity, with these, as with the electric arc, the exposure must be made with a shutter of some kind. A lens cap fitted with a safelight screen, or a simple flap shutter, is a decided convenience in placing the paper in position or in arranging for shading or other controls in printing.

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[6] A simple method of constructing such a scale has been outlined by Lockett, *Brit. J. Phot.*, 71 (1924), 171.

Methods of determining the proper exposure from measurements of the brightness of the projected image, or the transmission of the negative, have been published, and apparatus for making such measurements is available commercially.

Extensive experiments on this problem as applied to the exposing of motion picture negatives have been made by Tuttle, who found that the best results are obtained when the exposure is based on the mean of the maximum and minimum transmission of the image. Exposures based upon total transmission are satisfactory in many cases, but are subject to error when the object of principal interest is comparatively small and is surrounded by a background of much lower or higher density.[7]

Usually, as in contact printing, the proper exposure is found by trial and error, using test strips. At times, it is difficult to determine the best exposure from a test strip as the same part of the subject is not included in the different exposures. In such cases, a method suggested originally by Mente may be found useful. An opening is cut in a sheet

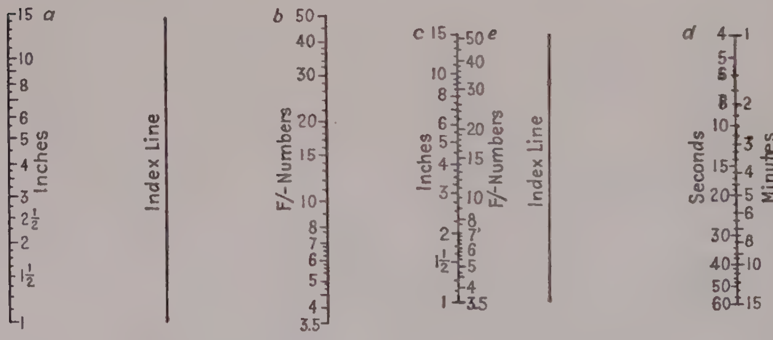
[7] Tuttle, C., "On the Assignment of Printing Exposures by Measurement of Negative Characteristics," *J. Soc. Mot. Pict. Eng.*, **10** (1932), 172.

Adamson—An Exposure System for Enlarging. Brit. J. Phot., **73** (1926), 475–477.
Dunn—Practical Method of Estimating Printing Exposures and Contrast by Densitometer. Brit. J. Phot., **84** (1937), 37.
Henderson—Finding Exposures in Bromide Enlarging. Brit. J. Phot., **62** (1915), 448.
Jacobs—Exposure in Artificial Light Enlarging. Amer. Phot., **15** (1921), 490.
King—Calculation of Exposures in Enlarging. Brit. J. Phot., **53** (1906), 188.
Lockett—The Calculation of Exposures in Daylight Enlarging. Brit. J. Phot., **52** (1905), 845.
Sellors—Method of Calculating Exposures in Enlarging. Brit. J. Phot., **70** (1923), 349.

of opaque cardboard, which is placed on the easel in such a way that the opening is over an important part of the picture. One side of the cardboard is attached to the easel with adhesive tape. A test strip is then placed beneath the cardboard and moved between exposures in order to obtain a series of exposures of the same part of the subject on the one strip.

The time of exposure is the same, under the same conditions, for a contact print as for an enlargement, if the contact print is exposed in the same plane as the projected image and with the equipment set for the required degree of enlargement.[8] Consequently, if the apparatus is set for an enlargement, the time of exposure may be found by placing the negative on the easel and making test exposures. The exposure producing a satisfactory contact print will be correct for the projected print, if the same paper is used.

Relative Exposure, Scale and Aperture in Enlarging or Reducing.—When the best exposure has been found for a given negative at a certain size of enlargement, the time of exposure at any other degree of enlargement or reduction is easily found, provided condensers are not used. Perhaps the most convenient method of making such calculations is by the charts described by Capt. S. M. Collins.[9]



In the general problem of exposure there are three factors which may all vary; these are: the size of the picture, the aperture of the lens, and the duration of the exposure. Any two being known, the other can be found. The following scales provide a means of making these calculations. From Chart I is read the alteration in the f: number required when varying the size of reproduction to obtain the same exposure. In Chart II, *C* and *D* show the mutual relation of size and exposure if the same f: number is retained, and scales *E* and *D* connect the f: number and the exposure when it is necessary to change either without varying the size.

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[8] A. Lockett; *Brit. J. Phot.*, 77 (1930), 743.

[9] *Brit. J. Phot.*, 70 (1923), 31.

To find the proper diaphragm when it is desired to alter the size of reproduction, but not the exposure, using Chart I, run the edge of a ruler from the size of the image to the aperture used. Mark the position at which the ruler cuts the index line. From this position run the ruler to the new size of reproduction. The other end of the ruler cuts the aperture scale at the proper aperture to employ.

To determine the time of exposure with the same aperture for another degree of reproduction scales *C* and *D* of Chart II are used. The straight edge is applied to the scales to cut scale *C* at the size of image for which the proper exposure is known and scale *D* at the time of exposure. Mark on the index line the point of intersection as before and join this point to the corresponding size of image on scale *C*. The other end of the ruler will then cut the scale *D* at the proper time of exposure for the new size of reproduction.

The aperture required for any given exposure when that for a particular is known may be calculated from scales *D* and *E*. With the edge of a ruler join the aperture on scale *E* with the corresponding exposure on *D*. From the point of intersection with the index line, transfer the ruler so that it passes through the exposure required on scale *D*. Then the other end cuts scale *E* at the proper aperture to use.

Introducing Clouds in Enlargements.—In the case of landscape negatives with a bald-headed sky, it is often possible to improve the pictorial effect considerably by printing in clouds from another negative. While there are several ways of doing this, the method to be described is as satisfactory as any and is perhaps the most generally useful. The image of the landscape negative is first focused on a sheet of thin cardboard placed on the easel. On this sheet of cardboard the outline of the skyline is traced with a soft pencil. The cardboard is now removed and cut along the pencil line. The upper piece will serve to mask the sky portion while making the exposure for the landscape; the lower portion, masks the landscape while the cloud is being printed.

This much done, the bromide paper is placed in position and the proper exposure given for the landscape portion, masking the sky portion by the sheet of cardboard. It is not often that the sky portion requires any masking, but when it does the appropriate mask is held close in front of the bromide paper and kept in slight up-and-down movement with the cut-out outline in close register with the image. Now the orange cap is replaced on the lens and trace the outline of the sky lightly on the bromide paper with a soft lead pencil. Then, without moving the paper, the landscape negative is replaced with the cloud negative and adjust the latter so as to secure the clouds in the desired position. Next the other mask is brought in in such a position as to cover the landscape portion and make the exposure for the clouds, keeping the mask moving up and down as before.

If the proper times of exposure for the two negatives have been accurately determined by exposing pairs of test strips and developing the two together for the same time, this procedure should result in a satisfactory effect.

Of the aesthetic factors in the combination of landscape and sky from separate negatives, it is not within the province of this work to speak. The worker's sense of the aesthetic and his knowledge of nature must ever be on guard in combination printing in order that the result be true to nature and satisfactory to the artistic sense.

Control in Projection Printing.—Much may be done to improve the print by judicious shading during the exposure. Shading may be utilized both for "holding back," i.e., making lighter, or for "printing in," i.e., making darker. The methods employed are essentially the same, only the object is different.

"Printing in" is accomplished by means of opaque cards with an opening of suitable size and shape held between the lens and the image. The nearer the card to the easel, the smaller the area covered and the sharper is the image. Hence for "printing in" small areas where the light must be sharply confined, a small opening held near the image will be used. For printing in larger areas the same opening can be used and the card moved back unless it is necessary to shade closely to a line, in which case it is better to use a larger opening nearer the image. The shape of the opening varies with that of the area to be printed in if the entire area is to be uniformly printed in. Large areas, however, frequently necessitate local work requiring a smaller opening.

The shape of the opening may be altered in many cases to conform with the subject by inserting one or more fingers in the opening in such a way as to make it the desired shape.

Any portions of the image which require lightening may be held back by shading, during a part of the exposure, with a piece of cardboard or if small, a piece of cotton attached to a small wire. This should, of course, be kept in motion during the exposure. The sharper the edge of the area to be shaded, the nearer the card should be to the sensitive paper.

Where an area with a definite edge is to be held back, or printed in, the surrounding area may be protected by a mask cut in a sheet of paper sufficiently opaque to prevent any material exposure of the sensitive paper beneath. If this mask is laid in contact with the paper the edge must be smoothly cut and follow the outlines of the area exactly. Since this is difficult, it is better to support the mask by a sheet of good quality glass, placed several inches above the sensitive paper, so that the shadow of the mask on the sensitive paper is slightly diffused. The mask may be prepared readily by placing a light yellow non-actinic paper on the glass, sketching in the area to be printed with a lead pencil, and then cutting it out with a sharp knife.

Diffusion of the Image in Projection Printing.—It should be noted at the start that the diffusion produced by the methods about to be described, while frequently an improvement, is quite different from that produced with soft-focus lenses, or other means of producing a diffused image in the making of the negative. Diffusion introduced in the making of an enlargement is more or less general for all parts of the image, while that introduced in the original negative varies with the different planes of the subject. Moreover, when diffusion is introduced in the negative, a light halo around the highlights of the subject spreads into the adjacent shadow portions, producing an effect which corresponds more nearly to the visual impression than the reverse effect, namely, a dark halo extending into the highlight areas, which is characteristic of the diffusion introduced in projection.

There are several methods of diffusing the image in projection printing:

1. *The use of a soft-focus lens.* The amount of diffusion is controlled by the diaphragm.

2. *Diffusion disks.* Disks of ribbed glass, or perforated celluloid, for use over the lens are available commercially, usually in several series to produce different amounts of diffusion. The amount of diffusion may be varied still further by making a part of the exposure with the diffusion disk and the remainder without.

Extra thin black chiffon or tulle placed in a cap over the lens produces similar results, but the time of exposure is increased and the contrast of the image reduced. White material reduces the contrast of the image to a greater degree than grey or black. One or more thicknesses may be used according to the degree of diffusion required.

3. *Diffusion screens placed near the sensitive paper.* Screens of silk bolting-cloth placed in contact with, or an inch or so from, the sensitive paper are favored by many workers. The silk bolting cloth used for this purpose can be obtained from dealers in photographic supplies in a fine or medium mesh and must be kept free from creases. Wooden frames may be used for this purpose, or the cloth may be attached to a sheet of glass using adhesive tape along the edges. When placed in contact with, or very close to, the paper, the lines show, producing a screen effect. A general softening of both definition and contrast is obtained when the screen is placed a short distance from the paper. The degree of diffusion may be varied by altering the distance between the screen and the paper, or by making a part of the exposure without the screen.

Enlarging from Wet Negatives.—It is a very common practice among press photographers to enlarge from wet negatives in order to save the time required for drying. The wet film, after it has been washed briefly, is sandwiched between glasses under water, the outside of the glass, is cleaned with a dry, lintless cloth, and the enlargement made. A special wet-film holder is supplied by the Eastman Kodak Company for use with the Eastman Auto-Focus Enlarger. For other types of enlargers the Eastman Processing frame may be used for the same purpose. This consists of two non-corrodible metal frames, each with one side turned over to act as a flange. The two fit tightly together with the film between held firmly along the full length of each of its four sides. This holder keeps the wet film flat without the use of glass on either side. If there is any danger of the wet film softening from the heat, it should be placed in a 5 per cent solution of formaldehyde for three or four minutes.

Correction of Distortion in Projection Printing.—The convergence of parallel lines, produced, for example, when tilting the camera to include the whole of a building without adjusting the swing back to a vertical position, may be corrected in making a projection print by placing either the easel, or the negative carrier, or both if possible, at suitable angles to one another. Projection Printers with automatic

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Piper—Correction of Distortion Produced by Tilting Camera. Brit. J. Phot., **55** (1908), 694.

focusing or with lenses having only one diaphragm are not suitable for work of this kind as they do not permit the necessary adjustments to easel and negative carrier. In such cases, a new corrected negative may be made by copying a print from the original negative with the copy-board and swing back of the camera tilted to render the lines parallel.

Whether the correction is made in copying, or in projection printing, the procedure is as follows: With the negative and easel parallel to one another, adjust to size, and focus until the width of the middle line of the image is the size required. This distance of negative and easel is not to be altered. The middle line should also be on the optical axis so that swinging the easel, or the negative, will not throw it out of focus. Tilt the negative slightly in the required direction and tilt the easel until the image is again in focus. If the lines still converge, tilt the negative a little more, and the easel to correspond. When the lines are parallel, fix the tilt of the negative and do not alter. If the building appears too low, use the rising front to move the lens to place the image on the distant portion of the easel. To decrease the apparent height of the building, use the rising front to move the image on the easel in the direction of the lens.

This procedure may be used to alter the proportions of the image, as, for example, to increase the height of a building, trees, or a standing figure. The tall elongated figures demanded for fashion illustrations may be produced in this way. Grotesque effects are produced if the process is carried to extremes; a small amount of distortion, however, is not usually apparent and may at times increase the effectiveness of the picture.

CHAPTER XXI

TONING OF DEVELOPED SILVER IMAGES

Introduction.—The process by which the color of a print, or transparency, is changed through the replacement of the silver image with one consisting of a metallic compound or a dye is known as toning. Compounds of sulfur, iron, copper, lead, gold, uranium, tin, selenium vanadium and cobalt are used but the first mentioned is by far the most important. Dye toning processes are reserved almost exclusively for transparencies. Representative formulae and instructions for toning with these substances will be given in this chapter; for additional information on toning, reference should be made to the bibliography.

Sulphur Processes—The Print.—The color obtained upon toning depends in part upon the process but more particularly upon the emulsion and the exposure and development of the black and white image.

The smaller the average grain size of the developed image the warmer or more yellowish the color of the image after toning. Chlorobromide and chloride papers tend to produce warmer tones than those coated with an emulsion of silver bromide.

Although numerous statements to the contrary may be found in the literature, the particular developing agent employed has little effect on the color of the toned image. Development in solutions heavily restrained with a soluble bromide, however, result in warmer, i.e., more yellowish, colors, due to the finer grain of the reduced silver deposit.

The time of development is, with any particular paper and developing solution, a very important factor in determining the color of the toned image. Shortening the time of development results in warmer colors; lenghtened development in colder, more purplish tones; the limit being reached upon development to finality.

Less ← | → Greater

warmer colors ←——————|——————→ colder colors

With a given time, or degree of development, exposure is without effect on the color of the toned image and controls the depth or intensity only.

In practice, therefore, the color of the image with any particular paper and developer may be controlled within certain limits, by variation (1) of the amount of soluble bromide in the developer and (2) the time of development.

When developing for a fixed time, the developer should be renewed frequently or the accumulated bromides and restraining by-products of the reaction will affect the color of the image when toned. The variation in color due to differences in the composition of the developer and the time of development is more marked in the toned than in the black image.

Prints intended for toning should be slightly darker than those to be left in their original state in order to allow for the reduction in depth which occurs in toning.

Hypo-Alum Process of Sulfur Toning.—The hypo-alum toning bath is prepared by dissolving ordinary alum (potassium aluminum sulfate) in a hot solution of hypo. The chemical reactions taking place are not definitely known and depend largely upon the temperature of the bath. Probably the first reaction is the formation of sodium sulfate and aluminum hyposulfite, the last mentioned decomposing into aluminum sulfate and sulfuretted hydrogen which reacts with the sodium sulfate forming acid sodium sulfite and colloidal sulfur.[1]

The colloidal sulfur thus formed reacts with the metallic silver constituting the image to form a brownish deposit of silver sulfide:[2]

$$2Ag + S \rightleftharpoons Ag_2S.$$

The reactions taking place in the toning in a solution of hypo and alum may be represented as follows:

$$Al_2(SO_4)_3 + 3Na_2S_2O_3 = Al_2(S_2O_3)_3 + 3Na_2SO_4,$$
$$Al_2(S_2O_3)_3 + 3H_2O = Al_2(OH)_3 + 3SO_2 + 3S,$$

or

$$Al_2(SO_4)_3 + 3H_2O = Al_2(OH)_3 + 3H_2SO_4,$$
$$Na_2S_2O_3 + H_2SO_4 = Na_2SO_3 + SO_2 + S,$$

and

$$Ag_2 + S = Ag_2S.$$

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[1] Seyewetz, A., and Chicandard, *Eder's Jahrbuch,* 10 (1896), 488.

[2] Sheppard, *Photography as a Scientific Implement,* 167.

NITZE—Paper, Developer and Bleach in Sulphide Toning. Brit. J. Phot., 79 (1932), 486–487.

A bath consisting of hypo and alum alone has a solvent action on finely divided silver causing the image to be bleached in the process of toning, hence the bath is first "ripened" through the addition of silver either as silver nitrate or by toning waste prints.

The following forms a satisfactory hypo-alum toning bath.

Cold water	90 ounces	2800.0 cc.
Sodium Thiosulphate (Hypo)	16 ounces	480.0 grams

Dissolve thoroughly, then add the following solution:

Hot water (about 160° F.) (71° C.)	20 ounces	640.0 cc.
Potassium Alum (E. K. Co.)	4 ounces	120.0 grams

Then add the following solution (including precipitate) slowly to the above hypo-alum solution while stirring the latter rapidly.[3]

Cold water	2 ounces	64.0 cc.
Silver Nitrate (Crystals) (E. K. Co.)	60 grains	4.2 grams
Sodium Chloride (Table salt)	60 grains	4.2 grams
After combining above solutions, add water to make	1 gallon	4.0 liters

Note: *The silver nitrate should be dissolved completely before adding the sodium chloride, and immediately afterwards the solution, including the milky white precipitate, should be added to the hypo-alum solution as directed.*

For use, pour into a tray standing in a water bath and heat the toning bath to 120° F. (49° C.). Never use the bath if the temperature is above 120° F. (49° C.) or blisters and stains will result. Prints will tone in 12 to 15 minutes depending upon the grade of paper. Toning should not be continued longer than 20 minutes at 120° F. (49° C.).

The formation of a black or gray precipitate in the bath in no way impairs the toning action of the bath if proper manipulation technic is used.

Prints should be immersed thoroughly and separated occasionally, especially during the first few minutes, to insure even toning. The black prints should be a shade dark and developed from 1½ to 2 minutes without forcing, to produce good sepia tones. After prints are toned, sponge off any sediment in warm water and wash for one hour in running water. Dry prints should be soaked thoroughly in water before toning.

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[3] The addition of ammonia, sodium phosphate or potassium iodide is sometimes recommended. Ammonia: *Brit. J. Phot.*, 68 (1921), 773; 70 (1923), 570. Sodium phosphate: *Brit. J. Phot.*, 51 (1904), 1022. Potassium iodide: *Brit. J. Phot.*, 67 (1920), 437.

The time required for toning may be reduced by placing the fixed and washed prints in a 10 per cent solution of sulfuric acid (commercial) for one minute and then transferring directly to the toning bath.[4] Toning then proceeds rapidly.

The addition of gold chloride results in darker and colder (more purplish) colors. The toned image in this case consists of gold sulfide and silver sulfide, the latter predominating.

The following is a satisfactory formula for a hypo-alum-gold toning bath:

Solution No. 1

Warm water (about 125° F.) (52° C.)	1 gallon	4.0 liters
Sodium Thiosulphate (Hypo)	2 pounds	960.0 grams
Ammonium Persulphate	4 ounces	120.0 grams

Dissolve the hypo completely before adding the ammonium persulphate. Stir the bath vigorously while adding the ammonium persulphate. If the bath does not turn milky, increase the temperature until it does.

Prepare the following solution and add it, including precipitate, slowly to the hypo-persulphate solution while stirring the latter rapidly. *The bath must be cool when these solutions are combined.*

Cold water	2 ounces	64.0 cc.
Silver Nitrate (Crystals) (E. K. Co.)	75 grains	5.2 grams
Sodium Chloride (Table salt)	75 grains	5.2 grams

Note: *The silver nitrate should be dissolved completely before adding the sodium chloride.*

Stock Solution No. 2

Water	8 ounces	250.0 cc.
Gold Chloride	15 grains	1.0 gram

For use, add 4 ounces (125 cc.) of Solution No. 2 slowly to Solution No. 1 while stirring the latter rapidly. The bath should not be used until it has become cold and has formed a sediment. Then pour off the clear liquid for use. Pour the clear solution into a tray standing in a water bath and heat to 110° F. (43° C.). The temperature, when toning, should be between 100° and 110° F. (38° and 43° C.). Dry prints should be soaked thoroughly in water before toning.

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[4] *Brit. J. Phot.*, 69 (1922), 126.

Keep at hand a black-and-white print for comparison during toning. Prints should be separated at all times to insure even toning. When the desired tone is obtained, rinse the prints in cold water. After all have been toned, return them to the fixing bath for five minutes, then wash for one hour in running water.

The bath should be revived at intervals by the addition of gold solution No. 2. The quantity to be added will depend upon the number of prints toned and the time of toning. For example, when toning to a warm brown, add 1 dram (4 cc.) of gold solution after each fifty 8 x 10-inch prints or their equivalent per gallon (4 liters) have been toned. Fresh solution may be added from time to time to keep the bath up to the proper volume.

Sulphur Toning with Acid Hypo.—When an acid is added to a solution of hypo, the latter is decomposed, one of the products of the reaction being finely divided sulfur. This reacts with the metallic silver of the image to form silver sulfide. A number of toning processes based upon this principle have been published. They are however but little used.[5] Toning is not completed within the bath itself but only after washing for thirty minutes to one hour to allow sufficient time for the colloidal sulfur to react with the silver image.[6]

Sulphur Toning with the Polysulfides.—A cheap and simple method of sulfur toning and one which produces acceptable results on many emulsions consists in the use of a polysulfide, or the inexpensive liver of sulfur, a mixture of potassium sulfide and potassium sulfate which usually contains impurities in the form of potassium carbonate and potassium hyposulfite.

The action of the polysulfide on finely divided metallic silver is probably as follows:[7]

$$S + H_2O \rightarrow H_2S + O,$$
$$Ag_2 + \rightarrow Ag_2O,$$
$$Ag_2O + H_2S \rightarrow Ag_2S + H_2O.$$

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[5] Lumière, A. and L. and Seyewetz, A., *Brit. J. Phot.*, **59** (1912), 972. Soar, H., *Brit. J. Phot.*, **60** (1913), 156, 185. Hoell, G. S., Eastman Research Laboratory, *Brit. J. Phot.*, **69** (1922), 73. Meuser, *Phot. Ind.*, 1916, 19; *Eder's Jahrbuch*, 1915, **29**, 408.

[6] Rawling, *Phot. Jl.*, **62** (1922), 3.

[7] Lumière, A. and L. and Seyewetz, A., *Brit. J. Phot.*, **70** (1923), 733.

Using liver of sulfur the following formula is satisfactory:

Liver of sulfur	¼ oz.	125 gm.
Hypo	½ oz.	25 gm.
Water to	20 oz.	1000 cc.

Use at a temperature from 80 to 90° F. (27–32° C.). Toning requires from ten to fifteen minutes but the final color becomes apparent only upon washing for several minutes.

Since the actual toning agent is the polysulfide contained in the liver of sulfur it is plain that this may be used. It may be prepared by dissolving pure sulfur in commercial ammonium sulfide until a saturated solution is produced and then withdrawing the clear solution for use. For toning, from ten to fifteen drops are added to ten ounces of water (2 cc. to 1000 cc.) and heated to a temperature of 85 to 90° F. (30–32° C.). Toning proceeds rapidly and is usually complete in 10–15 minutes.[8]

The addition of 2 per cent of potassium sulfocyanide increases the rate of toning but has little effect on the color, which however tends to purple.[9]

Direct Sulfiding Baths Employing an Oxidizing Agent.—Processes of this type depend upon the use of an oxidizing agent which convert the silver image into a salt which is immediately attacked by the sulfiding agent and converted into silver sulfides.

A number of agents have been employed for this purpose, among them ammonium sulfocyanide,[10] potassium ferricyanide alone and in conjunction with potassium bromide[11] and nitrobenzene.[12]

The following formula utilizing ammonium sulfocyanide produces on many papers a tone similar to that obtained by gold toning of print-out papers:

A.	Ammonium sulfocyanide	8 oz.	455 gm.
	Water to	16 oz.	1000 cc.
B.	Sodium sulfide	2⅔ oz.	152 gm.
	Water to	16 oz.	1000 cc.

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[8] Underberg, E., *Brit. J. Phot.*, **71** (1924), 50.

[9] Bullock, E. R., *Brit. J. Phot.*, **68** (1921), 450.

[10] Punnett, *Brit. J. Phot.*, **56** (1909), 571. Potassium persulfate. Kropf, *Brit. J. Phot.*, **57** (1910), 837.

[11] Triepel, *Brit. J. Phot.*, **58** (1911), 657. Mente, *Jahrbuch*, **26** (1912), 507. Blake-Smith, *Brit. J. Phot.*, **57** (1910), 520.

[12] Shaw, *Brit. J. Phot.*, **70** (1923), 267, 591.

The toning solution is prepared by mixing *directly before use*

A	8 parts
Water	24 parts
B	1 part

Toning requires from 15–40 minutes at a temperature of 70° to 80° F. (21–27° C.) or 5–15 minutes at 90–100° F. (33–38° C.). A higher temperature is not advisable owing to the action of the sulfocyanide on the gelatin.

Using nitrobenzene a suitable formula is:[13]

Barium sulfide (saturated solution)	15 parts
Sodium meta-nitrobenzene sulfonate (10% solution)	1 part

Prints immersed in this solution tone to a good sepia within 3–5 minutes at a temperature of 60° F. (16° C.). The color varies greatly, however, with the paper.

The reaction taking place, according to Sheppard,[14] is as follows:

$$C_6H_5NO_2 + 4Ag + 2NaSH = C_6H_5\cdot NH\cdot ONa + NaOH + 2Ag_2S.$$

Indirect Processes of Sulfur Toning.—In the indirect process of sulfur toning the fixed and washed prints are first bleached in a solution of an oxidizing agent which converts the silver of the image into a compound which is capable of being converted into silver sulfide when the print is placed in a suitable sulfiding bath.

The color obtained with the indirect method of sulfur toning tends to be more yellowish than that produced by the direct processes which are on this account the more generally suitable for chloride papers. The indirect process, however, is especially well adapted to bromide papers which in many cases tend to produce a cold and rather purplish color when toned in the hypo-alum bath or by one of the other processes of direct sulfur toning. As with the other processes the color

[13] Shaw, *Brit. J. Phot.*, **70** (1923), 759.

[14] *Brit. J. Phot.*, **70** (1923), 679.

Backstrom and Bostrom—The Influence of the Bleaching Bath on the Colour Obtained in the Indirect Sulphide-Toning Process. Phot. J., **76** (1936), 607.

Jelley—A Cause of Yellowness in Sepia Toning. Phot. J., **72** (1932), 480–485.

Morris—Stains in Sulphide Toning. Brit. J. Phot., **80** (1933), 127.

Wiegleb—Methods of Sulphite Toning. Brit. J. Phot., **76** (1929), 344–346, 363–365, 375–377.

obtained depends primarily upon the paper and exposure and development of the print rather than on toning, although certain changes in the procedure (to be noticed later) do influence the final color.

Prints for toning by the indirect process should be thoroughly fixed and washed. Incomplete fixation results in discoloration of the whites from the conversion of the silver salts left in the print into silver sulfide.[15]

Thorough washing is essential since traces of hypo remaining in the print combine with the oxidizing agents used in the bleacher forming a reducer.

The commonest bleaching solution consists of potassium ferricyanide and potassium bromide; however, many other oxidizing agents may be used namely potassium or ammonium bichromate,[16] chromic acid, potassium permanganate,[17] ammonium persulfate, hypochlorite, and quinone.[18]

The reactions which take place in the case of a bleaching bath composed of potassium ferricyanide and bromide are probably as follows:

Bleaching

$$(1)\quad 4Ag + 4K_3Fe(CN)_6 = 3K_4Fe(CN)_6 + Ag_2Fe(CN)_6,$$

$$(2)\quad Ag_4Fe(CN)_6 + 6 + 4KBr = K_4Fe(CN)_6 + 4AgBr.$$

Sulfiding

$$2AgBr + Na_2S = Ag_2S + 2NaBr.^{19}$$

Slight, but relatively unimportant, differences in the color of the toned image result from variations in the composition of the bleaching solution.[20] Practically, bleaching solutions containing a bichromate are less desirable than one of ferricyanide and bromide because the first is less readily washed out of the paper while the second stains badly necessitating a clearing bath. A solution of 40 grams of potassium ferricyanide to a liter of water results in a more yellowish color than when the bleaching solution contains bromide. With a ratio of 3:1 for the ferricyanide and bromide, increasing the concentration of the former above 3 per cent tends to yellowness. The substitution of a chloride for bromide also results in more yellowish colors. Substituting 0.1 per cent of potassium sulfocyanide for the bromide results, with some papers, in a purplish color and slight reduction of the image.[21]

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[15] Lumière and Seyewetz, *Brit. J. Phot.*, **70** (1923), 732.

[16] *Brit. J. Phot.*, **56** (1909), 233; **64** (1917), 173.

[17] *Brit. J. Phot.*, **63** (1916), 659; **62** (1915), 353.

[18] Lumière and Seyewetz, *Bull. Soc. franç. Phot.*, **62** (1920), 267.

[19] Carnegie, *Brit. J. Phot.*, **53** (1906), 219, 947. Jelley, *Phot. Jl.*, **2** (1932), 480.

[20] Bullock, *Brit. J. Phot.*, **68** (1921), 447.

The following is a suitable formula for the bleaching solution:

Ammonium bromide	85 gr.	11 g.
or Potassium bromide	98 gr.	13 g.
Potassium ferricyanide	270 gr.	35 g.
Water to make	16 oz.	1000 cc.

The addition of sodium carbonate avoids yellowish colors.

Potassium bromide	65.6 gr.	15 gm.
Potassium ferricyanide	153.0 gr.	35 gm.
Sodium carbonate (des.)	32.8 gr.	7.5 gm.
Water to make	10.0 ozs.	1000 cc.

Sulfiding.—Sodium sulfide is generally used for this purpose although sulfur, other sulfur compounds may be used namely the corresponding barium and ammonium sulfides,[22] sodium sulfantiomoniate ($Na_3SbS_4 \cdot 9H_2O$),[23] sulphoxyphosphates such as Na_2SPO_3,[24] sodium sulphoxalate formaldehyde, $NaHSO_2 \cdot CH_2O \cdot 2H_2O$,[25] and thiomolybdates, thiotungstates, thiostannates and similar thio compounds.[26]

Only pure sodium sulfide should be used and it should be fresh as it oxidized readily forming caustic soda and hypo. The weakening of the sulfiding bath resulting from the use of impure sodium sulfide, an oxidized solution, or the presence of hypo results in yellowish tones. The caustic soda leads to softening of the gelatin and is a source of blisters. This may be avoided by the addition of an acid.

The odor of the barium salt is less objectionable than that of sodium sulfide, but insoluble carbonates and sulfates of barium are precipitated in the gelatin unless distilled water is used. The use of sodium sulfantimoniate (Schlippe's salt) results in an image consisting probably of some antimony sulfide as well as silver sulfide and colors ranging from an orange-red to much colder colors by the addition of ammonia.[27]

Sodium sulfide	1 g.	8 gr.
Hydrochloric acid	1 g.	8 gr.
Water to	1000 cc.	16 oz.

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[21] Bullock, *Brit. J. Phot.*, **68** (1921), 447.

[22] Namias, *Brit. J. Phot.*, **58** (1911), 324. *Brit. J. Phot.*, **54** (1907), 523.

[23] Blake-Smith, *Phot.*, **12** (1904), 30.

[24] Lumière, F.P. 507,332: *S. & I. P.*, Series I, **I** (1921), 4.

[25] Miller, *Phot. Ind.*, 1925, p. 1064.

[26] Smith, *Phot. Jl.*, **48** (1908), 267.

[27] Sedlaczek, *Brit. J. Phot.*, **53** (1906), 624, 645.

A tendency towards yellowish brown tones noticeable on certain papers (warm tone) may be avoided by placing the bleached and well washed prints for 15–20 seconds in a 1 per cent solution of sodium carbonate, rinsing and then sulfiding.[28, 29]

Another method, involving partial redevelopment of the image combined with sulfiding, consists in the use of a pyrocatechin developer with the addition of sodium sulphantimoniate ($Na_2SbS_4 \cdot 9H_2O$). The bleached and well washed prints are redeveloped in:

A.	Pyrocatechin	155 gr.	20 g.
	Sodium sulfite (des.)	385 gr.	50 g.
	Water to make	16 oz.	1000 cc.
B.	Sodium carbonate (des.)	650 gr.	85 gr.
	Water to make	16 oz.	1000 cc.

For use take 1 part *A* to 2 parts of *B* and add from 2–5 per cent of a 10 per cent solution of sodium sulphantimoniate. The color of the image may be regulated by varying the amount of sulphantimoniate in the redeveloper. Colors from red-chalk to a good sepia are obtainable on most papers.[30]

Gold Toning of Sulfided Prints.—Red colored images may be obtained by gold toning of the sulfide toned print. The gold toning bath is prepared as follows:[31]

A.	Gold chloride	10 gr.	1 gm.
	Water to make	6 oz.	300 cc.
B.	Thiocarbamide	15 gr.	1.6 gm.
	Water to make	6 oz.	300 cc.
C.	Citric acid	65 gr.	7.5 gm.
	Water to make	6 oz.	300 cc.

For use take:

A	1 part
Water	3 parts
B	1 "
Water	3 parts
C	1 "
Water	3 "

Finally mix the three solutions.

The sulfided and washed prints are placed in this bath and kept

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[28] Jelley, *Phot. Jl.*, **72** (1932), 480.

[29] Bullock, *Brit. J. Phot.*, **68** (1921), 447.

[30] Valenta, *Phot. Korr.*, **49** (1912), 279.

[31] Wiegleb, *Brit. J. Phot.*, **76** (1929), 377.

in motion to prevent uneven action. Toning requires from 15–25 minutes depending upon the paper and the color desired. The brown color of the sulfur toned print first assumes a reddish color and gradually approaches a pure red.

After toning the prints are washed for 2–3 minutes and fixed for 5 minutes in a fresh acid fixing bath, then well washed and dried.[32]

The gold toned image appears to consist of a double sulfide of silver and gold.[33]

Reduction of Sulfide Toned Images.[34]—If the print is too dark after toning it may be reduced by placing it for a few seconds in

Cupric bromide	230 gr.	30 gm.
Sodium chloride (salt)	4½ oz.	250 gm.
Water to make	16 oz.	1000 cc.

Toning with Stannous (Tin) Salts.—Processes of toning employing tin salts are of greater interest theoretically than practically. Unlike other toning processes in which the silver of the image is replaced or converted into a chemical compound, in the case of tin salts an adsorption compound of colloid silver is formed.

If stannous chloride is employed the following reaction may be regarded as taking place.[35]

$$Sn + 4OH = SnO_2 + H_2O,$$
$$2Ag + SnO_2 = 2Ag + SnO_2.$$

The prints are first bleached in a solution of ferricyanide and bromide, or copper chloride. The bleaching formula for sulfide toning (p. 442) is suitable.

The prints are then washed thoroughly and placed in a solution of sodium stannite prepared as follows:[36]

Stannous chloride	10 gm.
Water to	100 cc.

To this add with constant shaking 70 cc. of a 10 per cent solution of caustic soda until the precipitate first formed is redissolved. Finally add

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[32] With developed silver images the above gold toning bath produces a blue-black deposit. Gold toning may be beneficial in such cases if the original print is slightly muddy or greenish in color.

[33] Lumière and Seyewetz, *Brit. J. Phot.*, **70** (1923), 331.

[34] Smith, *Phot. Jl.*, **47** (1907), 281.

[35] Formstecher, *Brit. J. Phot.*, **68** (1921), 759.

[36] Formstecher, *Brit. J. Phot.*, **68** (1921), 759.

Water	80 cc.

This results in a purplish black color on bromide prints and a sepia-brown with chloride developing papers. Warmer colors may be obtained by using potassium stannite which is prepared in a similar manner using, however, 100 cc. of a 10 per cent solution of potassium hydroxide and 50 cc. of water to each 100 cc. of a 10 per cent solution of stannous chloride.[37]

Toning with Hydrosulfite.—Pleasing warm brown, purple brown and sepia tones are obtainable on many papers with an acid solution of sodium hydrosulfite. The formula follows:

Sodium hydrosulfite ($Na_2S_2O_4$)	56.0 gr.	2 gm.
Oxalic acid (5% sol.)	1 oz. 5 dr.	25 cc.
Water to	10.0 oz.	150 cc.

Toning requires from 20–40 minutes at a temperature of 65°. The odor produced by the decomposition of the hydrosulfite is decidedly unpleasant.

Toning Processes Employing Selenium.—Selenium is similar chemically to sulfur and both the alkali selenides and the acid compounds have been employed for toning alone and in combination with hydrosulfite.[38]

The following is one of the many formulas which have been patented: [39]

Sodium sulfide (20% sol.)	10 oz.	500 cc.
Red amorphous selenium	4.5 gr.	0.5 gm.

The selenium is added to the solution of sodium sulphide, stirred briskly, and left to stand for several hours at room temperature. The filtered solution produces purple brown and reddish brown colors depending upon the character of the paper.

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[37] References on toning with tin. Gamble & Woolley, *Brit. J. Phot.*, **60** (1913), 978. Formstecher, *Brit. J. Phot.*, **68** (1921), 759. Druce, *Brit. J. Phot.*, **69** (1922), 433.

[38] For a comprehensive survey of the subject see: Sedlaczek, *Brit. J. Phot.*, **5** (1928); **76** (1929), 6.

[39] G. P. 301,019 by Mimosa, A. G.

FORMSTECHER—History and Theory of Selenium Toning. Phot. Ind., **34** (1936), 1014.

MILBAUER—Selenium Toning. Phot. Korr., **65** (1929), 10–12, 45–47.

Mercury-Sulfide Toning.—The addition of mercuric chloride to a bleaching solution of potassium ferricyanide and bromide followed by sulfiding in the usual manner results in an image consisting partly of silver sulfide and partly of a mercuric compound. The colors obtained range from a normal sepia to a warm engraving black depending upon the relative proportions of the mercury compound and silver sulfide. The bleaching solution is prepared as two stock solutions;

A.	Potassium ferricyanide	1	oz.	100	gm.
	Potassium bromide	1½	oz.	150	gm.
	Water to make	9	oz.	1000	cc.
B.	Mercuric chloride	60	gr.	12.5	gm.
	Potassium bromide	60	gr.	12.5	gm.
	Water to make	5	oz.	500	cc.
C.	Sodium sulfide	1	oz.	100	gm.
	Water to make	9	oz.	1000	cc.

Color	*A*	*B*	Water	Rel. Exposure
Normal sepia	40 parts	— parts	480 parts	10 sec.
Cool sepia	40 parts	20 parts	480 "	9 "
Colder sepia	30 "	30 "	480 "	8 "
Brown-black	30 "	50 "	480 "	7 "
Engraving black	30 "	90 "	480 "	6 "

After having been bleached in a bleacher compounded as directed for the tone desired, the prints are washed briefly and passed through three successive baths of one per cent hydrochloric acid after which they are again washed and finally sulfided as usual.[40]

Copper Toning.—The range of colors obtainable with copper toning extends from warm black through various shades of brown to red chalk, the various colors following one another in a definite order as the action proceeds. The chemical reactions taking place are probably as follows:

$$CuSO_4 + 2KBr = CuBr_2 + K_2SO_4,$$
$$CuBr_2 + Ag = CuBr + AgBr,$$
$$CuBr + 2AgNO_3 = Cu(NO_3)_2 + Ag_2Br.$$

The following is a satisfactory formula. Two solutions are required as follows:[41]

[40] Bennett, *Brit. J. Phot.*, 68 (1921), 25.

[41] British Journal Formula.

A. Cupric sulfate	60 gr.	6.25	gm.
Potassium citrate (neutral)	240 gr.	25	gm.
Water to make	20 oz.	1000	cc.
B. Potassium ferricyanide	50 gr.	5.2	gm.
Potassium citrate	240 gr.	25	gm.
Water to make	20 oz.	1000	cc.

For use take equal parts. Should the prints appear purplish in the highlights increase the amount of potassium citrate in either *A* or *B*.[42]

Uranium Toning.—The range of tones obtainable by toning with uranium extends from warm-black, through various shades of brown to plum colors and various shades of red, terminating in a bright brick-red. The toning action is progressive, the various colors appearing in a definite order as the action is allowed to proceed.

As the image is intensified in the process of toning, the black and white print should be lighter than normal.

The chemical reactions occurring are probably as follows:

$$8Ag + 4(UO_2)_3[Fe(CN_6)]_2 = 2Ag_4Fe(CN)_6 + 3(UO_2)_4[Fe(CN_6)]_2.$$

Prints intended for toning in uranium should be thoroughly washed as the presence of hypo results in stain which cannot be removed.

The following formula is suitable:[43]

Uranyl nitrate	38 gr.	5	gm.
Potassium citrate	38 gr.	5	gm.
Potassium ferricyanide	15 gr.	2	gm.
Ammonia alum	77 gr.	10	gm.
Pure hydrochloric acid	2 min.	0.3	cc.
Water	16 oz.	1000	cc.

A print immersed in the above toning solution shows no change for about a minute, after which a slight brownish color becomes apparent. This gradually changes into reddish brown as the action proceeds. When toning has proceeded to the point desired, the print is washed for one to two minutes and placed in:

Potassium citrate	38 gr.	5 gm.
Sodium sulfate (not sulfite)	192 gr.	25 gm.
Water	16 oz.	1000 cc.

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[42] Other methods of toning with copper: Namias, *Bull. Soc. franc. Phot.*, 64 (1922), 26.

[43] Ferguson, *Phot. Jl.*, 25 (1900), 113. Sedlaczek, *Phot. Ind.*, 1924, 234. *American Photography*, 1925, 8.

Three or four such baths may be required to remove the yellowish coloration entirely. The print should then be washed in running water free from alkalis for a minute or so, then fixed for five minutes in a 0.5 per cent solution of hypo followed by washing in running water made acid by the addition of 0.1 per cent of glacial acetic acid.

Toning with Vanadium.—The following is a suitable formula:

Vanadium oxalate solution (20 per cent)	½ fl. oz.	50 cc.
Oxalic acid (saturated solution)	½ fl. oz.	50 cc.
Ammonia alum (saturated solution)	½ fl. oz.	50 cc.
Ferric oxalate solution		quant. suff.
Glycerin	½ fl. oz.	50 cc.
Potassium ferricyanide (10 per cent sol.)	48 min.	10 cc.
Water	10 oz.	1000 cc.

The vanadium oxalate solution is prepared as follows: Either of these salts can be made quite easily from ammonium metavanadate which is a comparatively inexpensive salt. To make the oxalate place 100 grams (3 oz. 230 grains) of ammonium metavanadate in a beaker or evaporating dish and add 460 grams pure oxalic acid. To this add 500 cc. (17 oz. 287 minims) distilled water stirring constantly all the while and then heat the mixture. As the temperature rises it forms at first a thick paste which becomes more fluid as the temperature rises while the color changes from white to orange-red and finally to a dirty gray-green. More water may be added and heating continued until a perfect solution is obtained. The color will then change to a brilliant blue and the total bulk of the solution can be made up to 1477 cc. (52 oz.) producing a 20 per cent solution of vanadium oxalate containing a slight excess of oxalic acid.

Toning requires from ten to fifteen minutes, after which the prints are immersed in a 10 per cent solution of sodium sulfate for five minutes, washed several minutes and dried. Fixing is unnecessary.

The result of toning in the above solution is to produce an image consisting partly of blue ferri-ferrocyanide and partly of yellow vanadium ferrocyanide, the two combining to produce a green. The only practical application of vanadium as a toning agent is for the purpose of producing green colored images.

Dye Toning.—The range of colors obtainable by toning with metallic compounds is rather limited; a much broader range is possible by dye toning. Dye toning should not be confused with tinting or staining. A dye toned image consists of a colored dye image in uncolored gelatin; in a tinted image the gelatin is more or less uniformly stained by the dye.

To produce the preferential deposition of the dye so as to form a dye image, it is necessary to convert the silver image into an inorganic compound which will cause the dye to come out of solution and precipitate on the compound. Such a substance is called a *mordant* and the dye is said to be mordanted. Silver ferrocyanide is a typical mordant. Consequently if a silver image is converted into an image of silver ferrocyanide and immersed in a solution of a basic dye, the dye is precipitated upon the silver ferrocyanide producing a mordanted dye image.[44]

A comparatively large number of inorganic compounds have been used as mordants; among them silver iodide,[45] various ferrocyanides[46] and sulphocyanides,[47] silver sulphide,[48] lead[49] and iron.[50]

Dye toning is reserved more particularly for transparencies although methods involving the application of the dye solution by brushes or cotton to the surface of prints on paper have been described.[51]

Silver ferrocyanide is one of the best mordants for basic dyes and the following is a satisfactory formula:[52]

Uranium Mordanting Bath.—

Uranium (uranyl) nitrate	8 pounds	114 grains	8.0 grams
Oxalic acid	4 pounds	57 grains	4.0 grams
Potassium ferricyanide	4 pounds	57 grains	4.0 grams
Water to make	120 gallons	32 ounces	1.0 liter

Directions for Mixing. The uranyl nitrate should be of good quality and should not contain an excess of free nitric acid. First dissolve each chemical separately in a small volume of water. Then add the oxalic acid solution to the uranyl nitrate solution and finally add the ferricyanide solution. If the uranyl nitrate is added directly to the potassium ferricyanide, a brown precipitate will be obtained which will not dissolve readily in the oxalic acid. After mixing, the bath should be light yellow and perfectly clear. The solution should not be exposed to light any more than necessary.

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[44] The theory of the mordanting of dyes as applied to dye toning is as yet incomplete. In general, however, the process appears to involve the mutual precipitation of oppositely charged colloids. Bullock, *Brit. J. Phot.*, **70** (1923), 352; *Amer. Phot.*, **17** (1923), 756.

[45] Traube, D. R. P. 187,289 of 1905, *Brit. J. Phot.*, **53** (1906), 942.

[46] Clark, *Scientific Publications Eastman Research Laboratories*, **2** (1915), 130. Traube, B.P. 147,005 of 1916, *Brit. J. Phot.*, **68** (1921), 328. Crabtree, U.S.P. 1,305,962 of 1917.

[47] Christensen, B.P. 132,846, *Brit. J. Phot.*, **66** (1919), 639.

[48] Robach, *Brit. J. Phot.*, **70** (1923), 363.

[49] Namias, *Brit. J. Phot.*, **56** (1909), 68.

[50] Mercer, *Brit. J. Phot.*, **42** (1895), 557. Crabtree, U.S.P. 1,389,742.

[51] Lumière and Seyewetz, *Brit. J. Phot.*, **73** (1926), 135; **74** (1927), 31. Garnotel, *Brit. J. Phot.*, **75** (1928), 153.

[52] This formula and the directions which follow are from "Tinting and Toning of Eastman Positive Motion Picture Film," Eastman Kodak Co., Rochester, N. Y. Fourth edition, 1927.

For use, take 1 part of stock solution and 4 parts water.

Time of Mordanting. Immerse the film (slide) at 65° to 70° F. (18° to 21° C.) until a very slight chocolate-colored tone is obtained and remove at once. If mordanting is prolonged, much beyond this point, inferior tones will be produced. With a new bath, this will require from 1½ to 2 minutes but the time will need to be increased as the bath ages. The solution may be revived at intervals by adding a little of the concentrated stock solution.

Time of Washing after Mordanting. Wash until the highlights are free from yellow stain which usually takes about 10 to 15 minutes. Do not prolong the washing for more than 20 minutes or some of the mordant will be washed out.

The Dye Bath

Dye....................	3¼ ounces	3 grains	0.2 gram
*Acetic acid, 10%.........	76.8 oz.	1¼ drams	5.0 cc.
Water to make..........	120 gal.	32 gallons	1.0 liter

* To convert glacial acetic acid into 10 per cent acetic, take 1 part glacial acetic acid and add it slowly to 9 parts of water.

Thoroughly dissolve the dye in hot water, filter, add the acid and dilute to volume with cold water.

The following dyes are suitable for toning:[53]

Safranine A	Red
Chrysoidine 3R	Orange
Auramine	Yellow
Victoria Green	Green
Methylene Blue BB	Blue
*Methyl Violet	Violet

* For methyl violet use one-quarter the quantity of dye given in the formula.

[53] The dyes listed are obtainable from Eastman Kodak Company, Rochester, N. Y., in quantities under one pound. Larger quantities should be purchased directly from the manufacturer, National Aniline Co., 40 Rector St., New York, N. Y.

Time of Dye Toning. Immerse the mordanted and washed film (slide) in the dye bath for 2 to 15 minutes according to the color desired. The quantity of dye which mordants to the image increases with time. In case an image is over-dyed, some of the dye may be removed by immersing in a 0.2 per cent solution of ammonia; then rinse after drying.

If, after dyeing 10 minutes, the image does not mordant sufficient dye, remove the film (slide), wash thoroughly, immerse again in the mordanting bath, wash, and re-dye.

Intermediate Dye Tones. Intermediate colors may be obtained either by mixing the dye solutions or by immersing the film (slide) in successive baths. For example, if a reddish-orange tons is desired, first tone for a short time in the Safranine bath and then in the Chrysoidine bath, or the two baths may be mixed in suitable proportions and the tone secured with a single treatment.

Dye Toning in Single Solutions.—It is possible to combine the mordanting and dye baths to form a single solution toning bath. The difficulty in most cases is the precipitation of the dye. A satisfactory method has been described by Crabtree and Ives.[54]

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[54] *Trans. Soc. Mot. Pict. Eng.*, **12** (1928), 967. Dye toning may be combined with various processes of chemical toning. Crabtree and Marsh, *J. Soc. Mot. Pict. Eng.*, **14** (1931), 57.

CHAPTER XXII

MOUNTING AND FINISHING THE PRINT

Print Trimming.—Many prints are greatly improved by judicious trimming which eliminates unnecessary or objectionable subject matter and improves the composition.

A convenient means of determining how a print should be trimmed is afforded by two L shaped pieces of cardboard or opalescent celluloid.

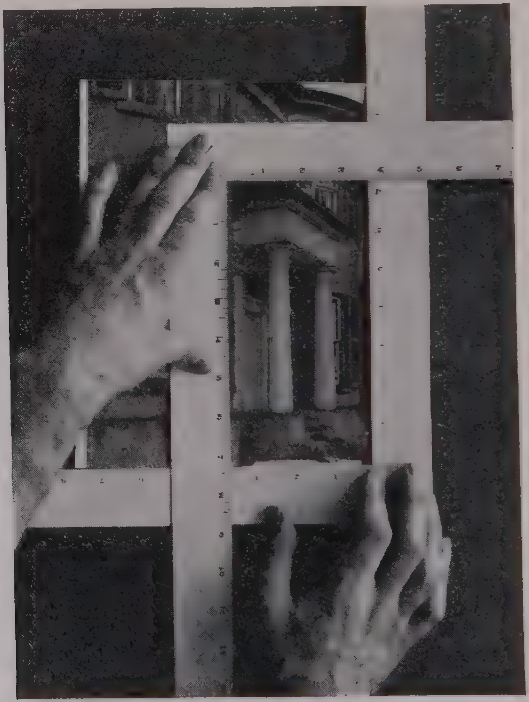

Fig. 202. Determining Proper Trimming

These may be placed on the print so as to form a frame the size and proportions of which may be altered at will and the effect studied. When the best composition has been decided upon, light pencil lines may be placed on the print as a guide for trimming. (A china marking pencil may be used with gloss papers.)

If the print is to be mounted with paste, it may be trimmed at once; prints to be dry mounted, however, should not be trimmed until the mounting tissue has been attached in order that both may be cut to exactly the same size.

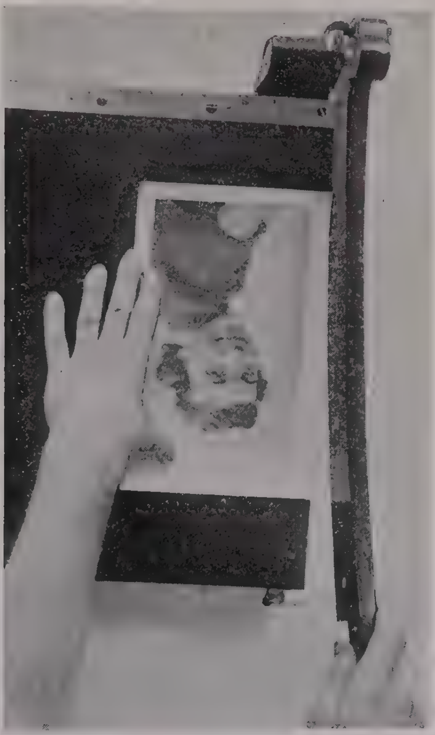

Fig. 203. Print Trimmer in Use

Prints are usually trimmed on a trimming board (Fig. 203). The print should be held firmly in place with the left hand to prevent slipping.

If a trimmer is not available or the print is larger than the blade of the trimmer, a straight edge and a sharp knife or a safety razor blade in a holder may be used. The print should be placed on a sheet of zinc, glass, wall board or heavy cardboard.

Oval or circular prints are best trimmed with the aid of metal trimming guides, which may be obtained in various sizes from the large dealers, and a swivel wheel cutter.

Mounting.—A print is not really complete until mounted. The function of the mount is to form a frame for the picture, a background which will separate it from its surroundings and display it more effectively. White or light mounts are preferred at the present time. A white mount, however, has the effect of increasing the apparent depth of the shadow portions of the print, especially if the margins are generous, and in such cases it is usually desirable to make the transition from the picture to the mount less abrupt by double-mounting (p. 455) so that the picture is enclosed within a narrow gray or black frame. In general this inner mount should be lighter than the darkest tones of the picture and darker than the highlights; if, however, the margin is a line, it may be a solid black.

The color of the mount is also important. A brown-black or sepia print, for example, will seldom appear to good advantage on a neutral grey or pure white. Usually it will appear to much better advantage on a warm grey, ivory or cream mount. On the other hand a cold grey print does not appear to good advantage on a warm-colored mount.

Mounting materials having a distinct color are in disfavor and brightly colored papers are undesirable even for toned prints.

The size of the mount is largely a matter of personal opinion although for exhibition purposes there are certain sizes which are recognized by the leading salons as standard. In general, the smaller the print the larger the mount may be in proportion.

In placing the print on the mount the usual practice with a vertical subject is to make the margins on the sides and top equal and that below the picture considerably wider. With a horizontal subject the usual practice is to make the margins at the sides and below equal and that above the picture somewhat less.

Types of Mounts.—The types of mounts to be described in this chapter are:

1. *The line mount* which consists of a narrow pencil or ink line on the mount around the picture (Fig. 204).
2. *The lined slip-in mount* (Fig. 204). This differs from the line mount in being in two pieces: (1) the front with a cut-out opening which frames the picture and on which the surrounding line is placed and (2) the back to which the picture and the front piece is attached.

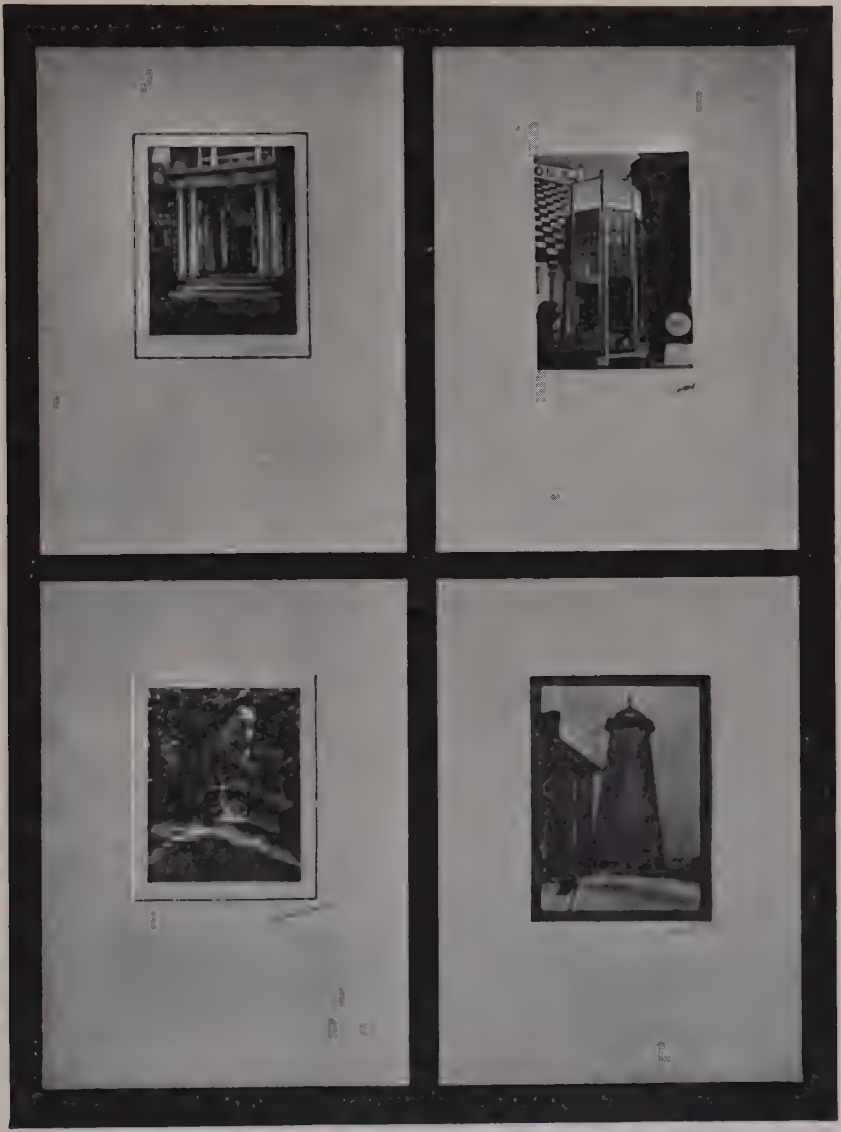

FIG. 204. Types of Mounts

Upper Left—Line
Upper Right—Cut Out
Lower Left—Embossed
Lower Right—Double

3. *The plate-sunk or embossed mount.* In a plate-sunk or embossed mount the center area occupied in part by the picture is depressed so as to produce the effect of a frame. The term "plate sunk" is derived from the depression produced by the plate when making a print from a copper plate etching. Frequently, photographic prints are made with wide margins and the paper sunk to produce the effect of an etching.
4. *Double mounting.* A double mount is made by mounting the print first on a sheet of thin mounting stock which is then trimmed to leave a narrow margin and then attached to a larger sheet of heavy mounting stock. The contrast between the first and second mount gives added emphasis to the picture (Fig. 204). In selecting papers for the two mounts it is usually desirable to avoid strong contrasts. The first, or inner, mount may be either lighter or darker than the other; in general, the greater the tone contrast between the two the greater the difference in the width of the margins.

To prepare mounts the following materials will be required:

Mounting papers.
Trimmer.
Sharp knife or safety razor blade in suitable holder.
Ruler.
Glue.
Pencil.
Black ink.

Papers suitable for mounting may be obtained from stationers, from printers by whom it is known as cover stock, and from artists' supply stores.

Preparing a Line Mount.—In preparing a line mount the print is first mounted and then the line placed around the picture. After the print has been mounted the position of the lines is decided upon. Two L-shaped pieces of cardboard may be used to advantage in determining the spacing which produces the best effect. The width of the margin is a matter of personal taste but in general the sides and the top will be equal and the bottom somewhat greater.

Mark lightly in pencil the positions of the lines on the mount. Then cut a piece of cardboard the size of the area enclosed within the lines. Place this on the mount so that its edges coincide with the marked positions, and then draw the lines around the card, using a soft lead pencil and taking care to make the corners neat. In some cases, the appearance is improved by retracing the lines with a pencil freehand.

Making a Lined, Slip-In Mount.—The pieces of cardboard which are to form the front and back parts of the mount are first cut to the approximate size. The color and quality of the card stock used for the back are not important as it is not seen. A piece of cardboard the size of the print is then cut and located on the cover of the mount in the position to be occupied by the picture. Draw a line around the card, and then with a straight edge and a sharp knife, or a safety razor blade in a holder, cut out the center portion cleanly.

Using the two L-shaped pieces of cardboard, determine the positions of the framing lines. Trace the lines lightly in pencil at first, then remove the cardboard guides and retrace the lines, using a straight edge.

The next step is to attach the front and rear portions of the mount. Apply a thin line of glue along the upper edge of the back portion, lay the upper half on it and place the two under pressure for several minutes.

Now apply a thin line of glue to the back of the print along the top and place the print in the proper position on the mount. Apply a thin line of glue along each of the three remaining sides of the mount and place under pressure for ten to fifteen minutes. Finally, trim the outside of the mount.

An attractive effect is produced by using either lighter or darker toned card stock for the front or cover portion of the mount and making it a trifle smaller than the rear portion so as to produce a narrow contrasting margin to the mount. In this case, the cover portion must be trimmed to the proper size before being attached to the back portion.

Making a Plate Sunk or Embossed Mount.—Mounting stock of suitable color and surface and not over 1/32 inch thick is first cut to the approximate size. The positions of the print and the embossed lines which will be placed around it are then marked with light pencil lines. A piece of cardboard the size of the area to be depressed is cut and attached to the mount with a drop of glue placed near the center of the area to be occupied by the picture. The mount is then turned over and the back moistened with a wet sponge along the lines to be embossed. Several minutes are allowed for the water to soak in and the edges of the card underneath are located with the fingers. The mount is now embossed, or depressed, along the lines of the card underneath by following the outline with an embossing tool (Fig. 205); care should be taken to make a clean cut and uniform impression.

When this has been completed, the cardboard is torn off and the print mounted, using either a thin line of glue along the top or by dry mounting. Finally, the pencil lines are erased and the outside edge trimmed to the proper size.

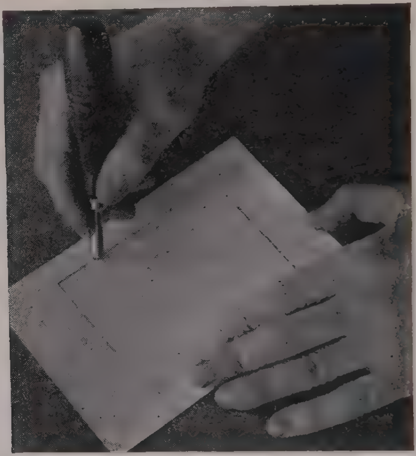

FIG. 205. Using Embossing Tool

Double Mounting.—First trim the print to the proper size and attach to the first mounting stock, preferably by dry mounting, otherwise by means of a thin line of glue placed on the back of the print along the upper edge.

Next trim the mount so as to leave the desired margins around the print. The width of the margins depends upon the size and character of the print and personal preference but should be greater at the bottom than along the three remaining sides.

Cut the card stock for the second mount a trifle large and indicate on it by light pencil lines the position of the mounted print.

Finally, attach the mounted print and trim the outside of the mount to the required size.

Commercial Mountings.—Mounts and folders (for portrait work) are available commercially, the latter particularly in large varieties. Unfortunately the artistic taste displayed in their design is frequently open to question and one is largely restricted to set sizes and proportions which may or may not be suitable for a particular print.

Folders designed for professional portraiture may be broadly divided into three classes: (1) *the inslip folder,* having an opening behind which the print is mounted (Fig. 206); (2) *the easel folder* and (3) *the corner pocket folder,* having small pockets at each corner into which the corners of the print are inserted.

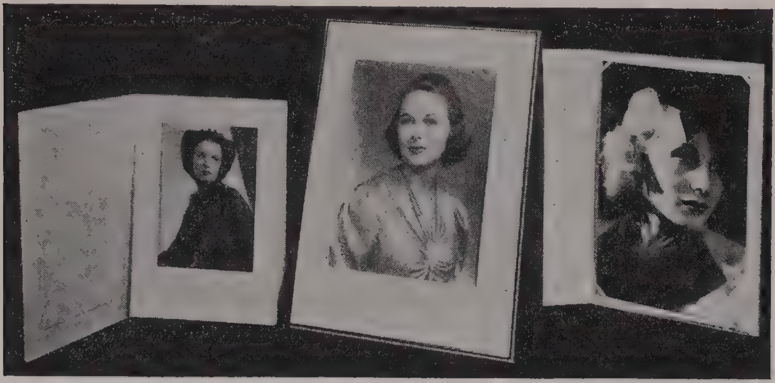

FIG. 206. Example of Folders Used for Professional Portraiture. Left to Right, Slip-in Folder, Easel Folder, Corner Pocket Folder

Mounting with Paste.—Prints to be mounted with paste should be trimmed first and then soaked in water for ten to fifteen minutes. Upon removal from the water they should be placed face down on a piece of heavy glass, or a ferrotype plate, and the surplus water removed by rolling with a print roller. Photo mounting paste is applied smoothly to the backs, using a broad, flexible brush. The print is then lifted up by inserting the finger nail or the tip of a knife under one corner and placed in position on the mount. Place a clean blotter over the print and go back and forth over it until the print adheres firmly to the mount. Lack of contact can be seen by holding the mounted print at an angle. Any raised places indicate insufficient pressure, a lump of paste, or an obstruction of some kind. If the latter, peel up one corner of the print, remove the obstacle, and go over the print with the roller a second time.

Finally, go over the surface of the print and along the edges with a moistened sponge, tuft of cotton, or cloth, to remove any paste which may have found its way to the surface of the print. Then place the mounted print on one side to dry.

Ferrotyped prints cannot be mounted with paste as the glazed surface is affected when the print is placed in water.

Dry Mounting.—Dry mounting is undoubtedly the most satisfactory of all methods of mounting. It is simple and convenient; the print is separated from any impurities in the mounting stock which might affect its permanency; and prints may be mounted on the thinnest of card without curling. It is the only really satisfactory method of mounting ferrotyped or colored prints solidly. Dry mounting tissue, which is a thin tissue coated with a composition which melts when heated, can be obtained in rolls or in cut sheets from dealers in photographic supplies and is inexpensive.

The print is first laid upon its face and a piece of dry mounting tissue of the same size attached to the back with the tip of a hot iron or an electric tacking iron. The tacking iron should not be too hot or the print may be discolored. The print is then trimmed *so that the tissue is trimmed with the print.* The print is then placed in the desired position on the mount, covered with a piece of thin cardboard and placed underneath a heated dry mounting press (Fig. 207) or a hot iron. From 15–30 seconds are required at a temperature of 185–225 degrees F. to melt the tissue. Several impressions will be required when mounting large prints with an electric iron in order to cover the surface. The weight of the iron is usually sufficient, but do not rub.

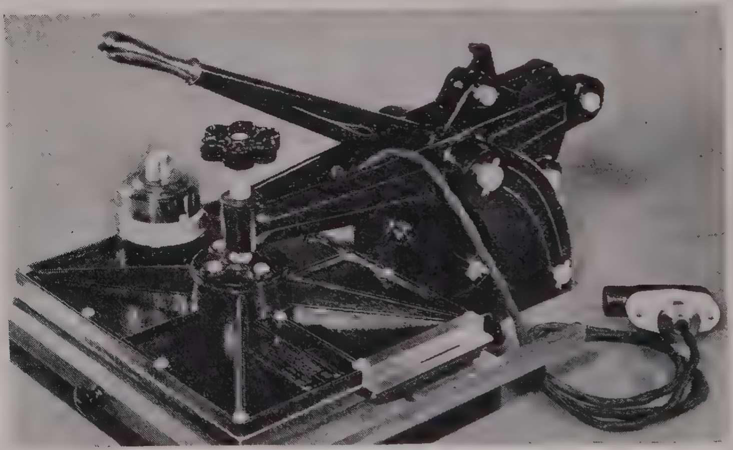

Fig. 207. Dry Mounting Press (Eastman)

If the print fails to adhere, leaving the tissue on the mount, the mounting press, or the iron, is too hot. If the print adheres to the tissue but not to the mount, the press is too cold. A temperature from 180–225 is satisfactory for most papers. Imperfect adherence of the print is usually due to uneven pressure. Irregular glossy markings or discoloration on the print are due to the press being too hot or the print being damp.

Backing Prints with Cloth.—Prints which receive considerable handling, as in salesman albums or in record books, are frequently mounted on cloth for added protection. Formerly, ordinary cloth was used for this purpose, but today, a special photographic mounting cloth similar to that used by bookbinders is generally employed. This stout cloth is coated on one side with an adhesive and is supplied in various weights and colors.

In mounting glossy prints, the wet print is first placed on the squeegee tin. A sheet of mounting cloth slightly larger than the print is then dipped in water momentarily, drained, and then laid over the print. Finally, the plate and its adhering print and cloth are squeegeed either with a print roller or wringer.

In mounting matt prints, the wet print is first placed on a sheet of heavy plate glass. The sheet of mounting cloth is then dipped in water momentarily, drained and then laid on the print. Finally, the print is squeegeed to the glass, then stripped and dried as usual.

Two matt prints may be mounted back to back by using the double photo mounting cloth having adhesive on both sides. One of the wet prints is placed face down on a sheet of heavy glass. The glass is placed on an illuminator or a printing machine, and the wet cloth laid down over the print. The second print is then placed in position, using the light from below to register the two prints. The prints and cloth are then stripped from the glass, squeegeed, and dried in the usual way.

Spotting.—After mounting, spots, either light or dark, should receive attention. Dark spots are usually the result of dust on the film at the time of the exposure and should be removed in the negative. If this has not been done, the etching knife must be used to scrape off the silver deposit from the spot until it matches its surroundings. If this is not done carefully, the spot may be made too light and it will be necessary to darken it with the spotting brush.

White spots are usually due to dust on the paper or negative when making the print. A little attention to the avoidance of dust at this stage will save hours in spotting the prints.

Colors for spotting photographs are supplied on celluloid cards containing four colors, black, white, cold brown and warm brown, but ordinary water colors may be used. A small sable brush (No. 1) is required. Moisten the brush between the lips and take up some of the color on the tip. Hold the brush vertically with respect to the surface of the print and bring the tip down on the print so that it covers the spot. If the amount of color deposited is insufficient and the spot is too light, take up more color and apply a second time. Should the spot be too dark, moisten another brush between the lips and remove some of the color until the spot matches its surroundings.

Spotting colors are not poisonous.

Large spots must be stippled in, using much the same touch as in retouching portrait negatives. If filled in solid they are made more conspicuous.

Waxing Prints.—Prints on matte papers are frequently improved by waxing. The shadows gain in depth and appear more lustrous. Commercial preparations are available for this purpose, or a solution of paraffin wax in gasoline may be used. This is applied with a soft cloth. A weak solution of gum arabic applied with an atomizer is also very effective.

Waterproofing Prints.—Prints which are to be displayed in the open without the protection of glass or are to receive much handling should be waterproofed. Commercial preparations (Kodalak W. P.) are available for this purpose, or the print may be immersed in the following solution:

Borax	300 gr.	30 gm.
Glycerin	300 minims	30 cc.
Shellac	600 gr.	70 gm.
Water	20 oz.	1000 cc.

Boil for one-half hour and add

Methyl alcohol	5 oz.	250 cc.

Varnishing Prints.—The following formula is suitable and results in a high gloss:

Transparent celluloid	1 oz.
Castor oil	⅛ oz.
Amyl acetate	16 oz.
Methyl alcohol	4 oz.

The transparent celluloid may be obtained from cleaned off film.

The dry prints are immersed in the solution for one minute, then drained, and hung up by one corner to dry.[1]

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[1] Moir, *Brit. J. Phot.*, **75** (1928), 343.

CHAPTER XXIII

LANTERN SLIDES AND TRANSPARENCIES

Sensitive Materials.—The sensitive materials available for lantern slides may be divided into three classes:

1. Rapid emulsions of silver bromide suitable for use in the camera or for contact printing. These comprise the majority of the lantern plates of American manufacture, for example, Eastman lantern plates, soft, medium and contrast, Hammer, Cramer and Ilford Special.
2. Slow emulsions of silver chloride designed for contact printing. These are nearly all of English or Continental manufacture, for example, Barnet Lantern Plate and Ilford Gaslight.
3. Medium speed emulsions of silver chloro-bromide, made especially for warm tones upon development. These are nearly all of English or Continental manufacture, for example, Barnet Verona, Criterion Mezzotone, Ilford Warm Black and Alpha lantern plates and Gevaert warm tone lantern plates.

The contrast of a transparency, like that of a negative, may be controlled by varying the time of development; a number of lantern plates, however, are made in more than one grade of contrast: both Eastman and Gevaert lantern plates, for example, are available in three degrees of contrast.

Plates of the first and third classes should be handled only in a bright orange or orange-red light such as that provided by a Wratten Safelight series O or OA. The slower materials of the second class may, in general, be handled with the safelights designed for contact developing-out papers.

The standard size for lantern plates in the United States and Canada is 3¼ × 4 inches; in England and the British Dominions (except Canada) 3¼ × 3¼ and in Europe 85 × 100 mm. (3⅓ × 4 inches).

For transparencies larger than lantern slides, ordinary slow plates or film may be used, but the degree of contrast obtainable on such materials is frequently insufficient unless contrast-type developers are employed. Transparency plates and positive films coated with emulsions similar to those employed for lantern slides are obtainable from many manufacturers of sensitive materials.

In recent years films (Adlux, Translite, etc.) and papers (Translite, etc.) coated on both sides with emulsions similar to those employed on contact printing papers have been introduced for transparencies. The object of the double coating is to increase the thickness of the emulsion so as to obtain the range of densities required in a transparency. In the case of paper, the emulsions are of different speeds, that on the back of the paper being faster to allow for the loss of light in passing through the first emulsion and the paper base.

Making Lantern Slides by Contact.—If the portion of the negative to be included in the slide is 2½ inches tall or less and not greater than 3 inches horizontally, then the slide plate may be made by contact printing. If the image is larger the slide must be made by reduction.

Either a printing frame or a printing machine may be used for contact printing. In either case, care should be taken to see that perfect contact is obtained. No mask of any kind should be placed between the negative and the slide plate as it affects the contact between the two. The undesired portions of the picture may be masked on the slide itself.

Since the slide is placed in the lantern with its longer dimension at the bottom, the image is placed vertically across the shorter dimension of the plate. Care should be taken that vertical lines in the picture, or the horizon line, are parallel with the sides of the plate.

It is well to cover the back of the slide plate with a piece of black velvet to reduce the danger of halation from light reflected back into the emulsion from the rear of the plate. Backed lantern plates may be obtained from some manufacturers but usually only on special order.

To determine the proper exposure, the plate may be exposed in strips by placing a card over the negative and successively covering or uncovering strips about ½ to ¾ of an inch wide. Calculation is simplified if the exposure intervals are equal.

Developers and Development.—A clear working developer which produces density and contrast readily is required. Hydroquinone and metol-hydroquinone developers are employed chiefly. It is preferable to use the formula recommended by the manufacturer.

Development is usually by inspection although the factorial method may be used. With many plates the time of development may be determined from the appearance of the image in the developing tray;

however, the better plan is to examine the image by transmitted light, holding the slide with the glass side away from the safelight.

Fixing, Washing and Drying.—After development, the plate should be rinsed briefly, but thoroughly, in running water or in a vessel of cold water and transferred to an acid fixing and hardening bath. In warm weather it may be advisable to harden the plate in a hardening stop bath of chrome alum before fixing.

Fixing will require from 5 to 10 minutes in a fresh acid fixing and hardening bath. Prolonged fixation is undesirable as the density of the image may be reduced, particularly if the bath is partially exhausted.[1]

One quart of fixing bath should fix from 75 to 100 slide plates if properly rinsed in water after development. Plates fixed in an upright position in a tank are cleaner than those fixed in a tray.

After fixing, the slide should be washed for 20 to 30 minutes in running water or in 6 to 8 changes of water, allowing five minutes for each change. Tests for the presence of hypo may be made using the methods described in Chapter 15.

Upon removal from the washing tank the surface of the slide should be wiped free of adhering dirt and precipitated substances, using wet absorbent cotton or a viscose sponge.

The slide should be dried in warm, dust-free air, but drying should not be forced by the application of heat. The effect of drying conditions on density and contrast are more marked in this case than with negative materials.

Slides by Reduction.—Slide making by reduction is simply rephotographing the negative on the lantern plate. Any focusing camera using plates or cut film larger than 3¼ × 4¼ inches may be used, with kits to adapt the plate holders for the lantern slide. A track of some kind should be provided to enable either the camera or the negative holder and its illuminator to be moved backwards or forwards.

Enlarging equipment may be used for reduction if the bellows extension is sufficient. In some cases it is possible to increase the bellows extension by constructing an extension cone, or supplementary lenses may be used to shorten the focal length of the lens and thus enable the apparatus to be used for reduction. Reducing attachments may be obtained for some projection printers.

Warm Tones by Development.—Brown and brown-black tones may be obtained on lantern plates with emulsions of silver bromide or silver chlorobromide by using developers containing a silver solvent such as ammonium carbonate or thiocarbamide. The effect of using such a developer is to produce an image consisting partly of relatively coarse particles of silver and partly of finely divided particles of silver which are deposited from the developer upon the development centers, or nuclei, existing in the exposed grains. The action of the developer is thus analogous to that of the so-called "physical" developers containing free silver, the silver in this case arising from the action of the silver solvent on the emulsion in the early stages of development.

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[1] "The Reducing Action of Fixing Baths," *J. Soc. Mot. Pict. Eng.* **18** (1932), 371.

The developers used for warm tones thus form a class intermediate in character between physical developers with added silver and typical chemical developers as used for negative development.

The variations in the color of the image produced with developers of this type are due to differences in the average size (or dispersity) of the silver grains which collectively make up the deposit. The relatively coarse grains comprising the image in the case of development with the usual developers result in a deposit which is practically free from selective absorption (except in the case of developers producing a pronounced stain image). A reduction in the average size of the silver particles results in deposits possessing selective absorption, producing, as the average size of the silver grains diminishes, images having a sepia, brown, purple, red or yellow color.

Emulsions of silver chloride are not, in general, suitable for the production of warm tones by development as they develop too rapidly and tend to fog in developers containing a silver solvent.

Warm Tone Development.—The formula which follows is due to Dr. B. T. J. Glover.[2]

Metol Hydroquinone Solution A

Hot water (120° F.)	500 cc.	16 oz.
Metol	5.0 gm.	70 gr.
Sodium sulfite (des.)	25.0 gm.	350 gr.
Hydroquinone	2.5 gm.	35 gr.
Sodium carbonate (des.)	18.0 gm.	250 gr.
Potassium bromide	0.5 gm.	7 gr.
Cold water to	1000 cc.	32 oz.

[2] *American Annual of Photography*, **46** (1930), 9.

Solution B

Cold water	160	cc.	8 oz.
Ammonium carbonate	20	gm.	1 oz.
Ammonium bromide	20	gm.	1 oz.
Water to make	200	cc.	10 oz.

In the table which follows are shown (1) the relative exposure times, (2) the composition of the developer, (3) the Watkins factor, and (4) the approximate color of the image.[3]

Relative Exposure	Developer		Watkins Factor	Color of Slide
	Solution *A*	Solution *B*		
5	8 dr.	—	10	Olive black
10	7 dr.	1 dr.	5	Sepia
20	6.5 dr.	1.5 dr.	5	Sepia-brown
32	6 dr.	2 dr.	5	Brown
96	5 dr.	3 dr.	5	Purple-brown
300	4 dr.	4 dr.	3	Red

The exact color varies with different slide plates.

As in the case of black and white slides, density is governed by the exposure, and contrast by the time of development. However, in the case of a developer containing a silver solvent the color as well as the contrast of the image changes with the degree of development. Beginning with a yellowish image the color changes first to red and then to purple, brown, sepia, and finally black as development progresses. Thus, with a given developer the contrast and color of the image are interdependent and neither can be modified without alteration of the other.

It is possible, however, by increasing or decreasing the concentration of the silver solvent present in the developing solution, to control

[3] B. T. J. Glover, *American Annual of Photography*, 44 (1930), 9.

Baker and Davidson—Studies in the Effect of Exposure and Development on the Color and Contrast of Warm Tone Slides. Brit. J. Phot., 71 (1924), 77.

Glover—Thiocarbamide and Blue Toned Lantern Slides. Brit. J. Phot., 70 (1923), 135.

Johnson—The Technics of Lantern Slide Making. Brit. J. Phot., 70 (1923), 237; Phot. J., 63 (1923), 58.

the time of development necessary for a given color. This enables the contrast of the image to be altered without producing a corresponding change in color. Thus, to counteract the effect of shorter development on the color of the image, the proportion of the *B* solution should be reduced, while to secure the same color with increased development, the proportion of *B* should be increased.

The time of exposure varies with the color. While color depends upon the time of development and is independent of the exposure, it is necessary to adjust the exposure to the time of development so as to obtain an image of the proper density. The shorter the time of development (i.e. the lower the development factor) the longer the exposure. The exposure required under any particular set of conditions must be determined by means of test exposures.

The color of the image cannot be determined precisely from the appearance of the slide during development because of (1) the color of the light transmitted by the safelight and (2) the difference in the appearance of the image when wet and after drying. Usually the color is colder and the density greater when dry than when wet. If the time of development required for a particular color has been determined, this time should be adhered to and the density of the slide regulated by the exposure. Variation in the composition and the temperature of the developer alters color and gradation; it is well to use a small volume of fresh solution for each plate and to use a water bath to maintain the proper temperature.[4]

Intensification and Reduction of Lantern Slides.—A slide which lacks brilliancy because of slight overexposure or a trace of fog may be improved by slight reduction in a subtractive reducer. In general, however, it is best to avoid the intensification or reduction of lantern slides, particularly those with warm tones, as the color and quality are adversely affected. If it is the exposure which is at fault then the slide should be made over; if an alteration in contrast is required and this cannot be accomplished by suitable modification of the time of development, then the negative should be reduced or intensified.

Varnishing.—While not absolutely necessary, it is well to varnish the slide. Varnishing prevents the "dewing" of the slide in the lantern from the condensation of moisture on the cover glass when heated. Suitable varnishes may be obtained from dealers in photographic supplies. The slide should be heated to drive off all the moisture before varnishing. With some varnishes the slide must be coated while still warm; others may be applied cold.

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[4] References on use of thiocarbamide for warm tone slides. Johnson, *Brit. J. Phot.*, 69 (1922), 595. Glover, *Brit. J. Phot.*, 70 (1923), 135. Johnson, *Brit. J. Phot.*, 70 (1923), 237.

Masking.—Black paper masks in various sizes may be purchased from dealers in photographic supplies. These, however, are seldom the exact size required for the best composition. Masks to fit the subject may be made by means of ruled adjustable mats, with lantern slide binding strips, or a suitable mask cut from black paper.

The mask should be at least ¼ inch wide or some of the picture will be cut off by the slide carrier of the lantern. The standard size opening for motion-picture theatre use is 2¼ × 3 inches.

Before binding, the slide should be marked to indicate to the lanternist the way in which it is to be placed in the lantern. Small disks of gummed paper are usually employed for this purpose. In the United States and Canada the standard practice is to place the spot in the lower left hand corner when the slide is held as it should appear on the screen. The lanternist places the slide in the lantern upside down with the spot acting as a thumb mark. In England the standard practice is to place two spots at opposite corners of the top of the slide, while in Europe a single spot placed in the lower right hand corner is used.

Binding.—The easiest method is to employ four separate strips of the gummed paper supplied by dealers as lantern-slide binding strips. Begin by cutting a number of strips of the binding paper into pieces 3¼ and 4 inches in length. Take a cover glass (a cleaned off lantern plate will do) and place it against the masked (emulsion) side of the slide plate. One of the binding strips is then moistened with a wet sponge and applied evenly along one edge. The thumb is then run along the edge so as to obtain good contact with the edge of the two glasses and the strip folded over along the sides. The other three sides are then bound in the same manner.

The continuous strip method requires more practice but is quicker. The binding strip is moistened and placed gummed side up on a blotter or a sheet of paper. The edge of the slide with its cover glass is then placed at one end of the strip, care being taken to get it in the center, and rotated so that it picks up the binding strip on all four sides. The binding strip is then creased along the sides and the corners folded over.

Lantern Slides Direct in the Camera.—In copying from books and other sources for lantern slides, the making of a separate negative may be avoided by photographing directly on the lantern plate and reversing the image from a negative to a positive. Reversal may be accomplished in one of two ways:

1. The negative image is developed, the slide rinsed, and the negative image removed with a bleaching solution which dissolves the finely divided metallic silver of the image. The plate is then exposed to light to render developable the silver halide remaining and developed to produce a positive image.

2. The developed negative image is bleached in a solution which dissolves the silver image and hardens the gelatin according to the density of the silver image. A positive image is produced by staining the unhardened gelatin with a dye, or combination of dyes, which are absorbed only by soft gelatin.

Lantern slide emulsions in general are not designed for direct reversal and it is difficult to obtain good results except with line subjects. The time and labor involved in making dye positives is such that it offers no real advantage over the usual method.[5]

Duplicate Negatives.—Duplicate negatives are useful (1) as a means of preserving valuable negatives, (2) to protect the original negative from possible damage when a large number of prints must be made, (3) to enable handwork to be carried out on the duplicate negative which might endanger the original, and (4) to provide the enlarged negatives required when prints larger than the original negative are to be made by carbon, gum-bichromate, platinotype or other printing processes not adapted to projection printing.

Duplicate negatives may be made by one of three methods:

1. By first making an intermediate positive and from this a duplicate negative. This is the usual method.

2. By using direct copy film which results in a negative image directly. Sensitive materials of this type are a recent introduction but appear to offer distinct possibilities.

3. By reversing the intermediate positive image to a negative. This method lacks sufficient flexibility and general reliability to make it practical.

Sensitive Materials for Making Duplicate Negatives.—A good duplicate negative should reproduce accurately the gradations of the original unless the contrast is to be altered in the interests of better printing quality. The definition and graininess of the image should not be markedly inferior to that of the original.

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[5] Lantern slides directly by reversal. Carnegie, *Brit. J. Phot.*, **56** (1909), 528; *Brit. J. Phot.*, **63** (1916), 661. Power, *Brit. J. Phot.*, **58** (1911), 194; (1916), 662. Braintree, *Brit. J. Phot.*, **61** (1914), 320; **63** (1916), 663.

The sensitive materials used in making the intermediate, or master, positive and the duplicate negative must be able to reproduce fine detail, be free from excessive graininess, and have sufficient latitude to reproduce correctly the full range of densities in the original. These requirements are most nearly met by the special duplicating films designed for the motion picture industry. These, however, are available only as standard motion picture film.[6] Lacking these, a slow, fine-grain, blue sensitive plate or film of the " commercial " type should be used. These are preferably backed to reduce halation. Plates and films intended for transparencies, in general, are unsuitable, except for originals of below normal contrast, as the exposure scale is too limited to result in satisfactory reproduction.

Exposure and Development of the Intermediate Positive and Duplicate Negative.—Faithful reproduction of the original involves (1) the exclusive use of the straight-line portion of the characteristic curves of the sensitive materials employed in making the intermediate positive and the duplicate negative and (2) development of the two to gammas which will result in a reproduction gamma of unity (p. 195). If the contrast of the original is to be altered, then the gammas should be adjusted so as to produce the desired reproduction gamma.

The appearance of a properly exposed intermediate positive is quite different from that of a transparency or lantern slide. Since for good reproduction it is necessary that the various densities of the positive image lie within the straight-line portion of the D log E curve of the film or plate used, it is evident that the highlights of the intermediate positive will not be clear but will have a distinct density and that the whole image will be denser and softer than a good lantern slide. In fact, to the inexperienced a good intermediate positive appears overexposed and under developed.

If sensitometric equipment is available, the minimum highlight density for correct reproduction with the sensitive material used is readily obtained from sensitometric strips developed under the same conditions and to the same gamma.

Lacking sensitometric data the result must be judged by visual inspection, the judgment as to quality being based upon the fidelity with which the gradations of the original are preserved rather than in the density of the image.

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[6] For types and characteristics see: *Motion Picture Laboratory Practice*, Eastman Kodak Co., 1936.

Fine grain developers are recommended for development and the time of development should be adjusted to reproduce the contrast of the original or, if a modification is desirable, the contrast required for good printing quality. Within the limits imposed by the plate or film, the contrast of the duplicate negative may be controlled by suitable alterations in the time of development.

As with the intermediate positive, sufficient exposure must be given in making the duplicate negative so that every gradation of the intermediate positive will be faithfully reproduced. Good duplicate negatives have no clear shadows, even when they are present in the original negative. The shadow portions of a duplicate negative, if properly made, are always somewhat gray, and while those in some scenes may be more dense than others, depending upon the range of brightness in the subject, none of them should be entirely clear.

Enlarged Negatives.—In making an enlarged negative there are two courses open: (1) an enlarged positive may be made from the original negative and the duplicate negative by contact printing from the intermediate positive or (2) a contact positive may be made and this enlarged to the required size. The first method involves a greater outlay for material but has the advantage that any local alterations which are needed to remove defects or to improve the composition are more readily made on the positive than on the negative as it is easier to see the effect of such alterations in the positive than on the negative.

Paper Negatives.—For broad pictorial effects where definition is not an important factor, paper is frequently employed for the enlarged negative and at times for the intermediate positive. The use of paper appeals particularly to those who wish to control the final results by altering tones, intensifying the highlights, deepening shadows or softening objectionable lines in the composition, as such work is more readily done on the back of paper negatives than on film or glass.

Any smooth, single-weight paper of suitable contrast which will produce sufficient density when viewed by transmitted light may be employed.

Transparency papers coated on both sides (Translite) show less grain and produce greater contrast than single-coated papers and are suitable for negatives which are lacking in contrast.

In using a single coated paper graininess may be reduced by placing the paper so that the coated side faces the easel, that is away from the lens. It is, of course, necessary to give more exposure with the paper in this position than when the emulsion side is next to the lens but the improvement as regards graininess makes it worth while. The suitability of the paper positive and negative are judged, of course, by their appearance with transmitted rather than with reflected light.

Considerable diffusion results when both the intermediate positive and the final negative are made on paper, and except for extremely broad effects, better results are obtained by making the enlarged intermediate positive on paper and the final duplicate negative on film. This method has the advantage of the paper negative as regards handwork on the intermediate positive and the advantages of film in printing from the duplicate negative.

The transparency of a paper negative may be increased by oiling. Little improvement is made, however, in graininess, and on the whole, little is gained by oiling. The oil must be kept from the face of the print and even with the greatest of precaution, in handling the oiled negative, oil spots are liable to get on the printing paper. Oiling also increases the liability of the negative to pick up dust, grit, and lint.

CHAPTER XXIV

PRINTING PROCESSES: CARBON, GUM-BICHROMATE, ETC.

The Carbon Process.—Ever since its introduction as a practical process, carbon has been recognized as one of the finest of printing mediums. In common with other processes, which depend upon the action of light upon chromic salts, the carbon process affords a wide variety of colors and surfaces. But even more important is the fidelity with which carbon reproduces the delicate tones of a negative. In this respect the carbon process is unsurpassed.

There are two variations in carbon printing known as single and double transfer. In the first case the image is reversed from right to left, while in the latter instance the image is non-reversed. Carbon tissue consists of paper coated with gelatin and pigment. Before use, it has to be sensitized in a solution of potassium bichromate and is then dried in the dark. With a spirit sensitizer, drying is very rapid and sensitizing is in operation which requires very little time. When dry, the tissue is exposed to daylight under the negative, a photometer being used to regulate the exposure, as the image is not visible. When exposure is complete the tissue is removed from the frame and allowed to soak until limp in cold water. In the meantime, a sheet of single transfer paper, or the temporary support if double transfer is to be made, is allowed to become pliable in the water. As soon as limp, the two are brought together and pressed into contact. After remaining under pressure a short while, the two are immersed in warm water and the tissue stripped off, leaving the gelatin and pigment adhering to the transfer paper, or to the temporary support in case of double transfer. Gentle washing in the warm water follows and the unacted upon bichromated gelatin with its pigment soon washes away, leaving the image in pure insoluble pigment. As soon as development is complete, the print is removed, placed in a bath of alum to remove the bichromate stain and harden the gelatin and is finally dried. Double transfer is a little more complicated. After development on the temporary support, the image is hardened and allowed to dry. It is then again placed in water and brought in contact with a sheet of double transfer paper.

The two are allowed to dry in contact and the paper may then be stripped from the temporary support carrying with it the image. Carbon is a comparatively simple and straightforward process and instructions unfortunately make it appear more involved than it really is.

The chemical reactions involved in the tanning or insolubilizing of a bichromated colloid upon exposure to light are still not definitely known. The neutral chromates, with the exception of ammonium chromate which decomposes in solution into ammonium bichromate, do not sensitize gelatin and the bichromates are not light sensitive except in the presence of organic matter. The investigations of Eder, Lumière, Seyewetz and others suggests that the bichromate or chromic acid is reduced to chromium sesqui-oxide Cr_2O_3, which then reacts with excess bichromate or to form a chromium chromate, which may be Cr_2CrO_6, and is the actual tanning or insolubilizing compound.

$$2H_6CrO_6 + \text{Light} \rightarrow Cr_2O_3 + 6H_2O + 3O,$$
$$Cr_2O_3 + CrO_3 \rightarrow Cr_2CrO_6 \rightarrow (3CrO_2).^1$$

Sensitizing Carbon Tissue.—Carbon tissue sensitized with potassium or ammonium bichromate does not keep well, becoming insoluble in a few days. The use of a neutral chromate such as potassium chromate results in a more stable tissue but of much lower sensitiveness. The sensitiveness may be increased, however, by suspending the tissue, before exposure, over a tray of glacial acetic acid in a closed chamber.[2]

Both the ammonium and potassium salts are used; ammonium bichromate is the more sensitive but the potassium salt is generally used on account [3] of its cheapness. The ammonium salt is more soluble in water, which is an advantage in a spirit sensitizer as a larger amount of alcohol or acetone may be added without causing precipitation. The sensitiveness of tissue sensitized with potassium bichromate is increased by the addition of ammonia or ammonium carbonate. Too much of either reduces rather than increases the sensitiveness of the tissue; approximately 0.2 per cent of ammonia (20 cc. to 1000 cc.) or one half the quantity of ammonium carbonate may be used. The

[1] Sheppard, *Photography as a Scientific Implement,* p. 171.
[2] Namias, *Brit. J. Phot.,* 67 (June 1920), 306.
[3] Lumière and Seyewetz, *Eder's Jahrbuch,* 1906, 184.

WALL—The Chromium Salts. Amer. Phot., **16** (1922), 613.
MIDDLETON—Some Experiments and Notes on Pictures in Pigments. Brit. J. Phot., **70** (1923), 735.

tissue also keeps better, as the occurrence of free chromic acid is prevented.

The sensitiveness and also the contrast vary with the concentration of bichromate in the sensitizing bath.

Concentrated solutions (4 to 6 per cent) result in greater sensitivity and low contrast; a dilute solution (1 to 2 per cent) produces higher contrast, although the time of exposure is longer. Contrast is affected to a certain extent by the color of the pigment; those which absorb blue and violet strongly tend to produce greater contrast.

If the tissue is to be used as soon as dry, a solution of potassium or ammonium bichromate may be used; if, however, it is to be kept for three or four days, a trace of ammonia (about .02 per cent) should be added.

The tissue may be sensitized by immersing it in the sensitizing solution, or the solution may be applied with a brush. Quick drying sensitizing solutions containing alcohol or acetone are usually applied with a brush. Tissue sensitized with a plain solution of bichromate requires several hours for drying, while with a quick drying sensitizer drying is usually complete within one-half to three quarters of an hour. For the occasional worker the use of rapid drying sensitizers is recommended.

Methods of Increasing Sensitiveness of Carbon Tissue.—The addition of a mild reducing substance to dichromated gelatin results in increased sensitiveness. Among the substances employed have been potassium ferrocyanide,[4] copper sulfate, copper chloride and cobalt chloride.[5] F. J. Tritton recommended that the tissue, after sensitizing in a 2 per cent solution of dichromate and exposing for ⅓ the usual time, be placed in a 2 per cent solution of cerous chloride for mounting instead of water. The time of immersion is stated to be practically without effect in the density or gradation of the image.[6]

Exposing the Tissue.—With single transfer the print is reversed from left to right. With many subjects this is not objectionable. It may be prevented in the case of film negatives by reversing the position

[4] Weingarten, U.S.P. 1,564,161 (1925).

[5] Valenta, *Phot. Korr.*, 1914, 327. Eder, *Phot. Korr.*, 1914, 326.

[6] *Brit. J. Phot.*, 76 (1929), 361. Luxor Film G.M.B.H. patented the fuming of dichromated gelatin layers with an organic acid, such as acetic, after exposure and before development to reduce the exposure. B.P. 289,858 of 1927.

Warburg—Dyes as Sensitizers of Carbon Tissue. Phot. J., **57** (1917), 169.

of the negative and printing from the back. Glass negatives may be printed from the back also if a single source of light such as an electric arc is used at a distance of several feet and the printing frame is not moved during the exposure.

A mask must be used in printing to prevent the pigment image from leaving the support during development. The mask should be at least ½ inch wide.

Either daylight or strong sources of artificial light such as the white flame arc, mercury vapor tubes, or Photoflood lamps may be used for the exposure. When daylight is used, diffused light is preferable to direct sunlight which may cause the tissue to become insoluble. The tissue must be kept dry while exposing and in damp weather a sheet of waxed paper, or cellophane, should be placed back of the tissue. A substantial printing frame with strong springs is required to ensure good contact between the stiff tissue and the negative.

When printing by daylight the time of exposure must be determined by means of an actinometer which consists of a scale of numbered densities. A strip of printing-out paper is placed beneath the density scale and exposed to light beside the printing frame. The amount of exposure is determined by examining the paper strip and noting the highest number visible in the print-out image. The number which represents the proper exposure for a particular negative must first be determined by trial. With experience it may be estimated with a fair degree of accuracy.

With artificial light it is usually sufficient to expose by time. Special precautions should be taken to avoid heating the tissue which results in a general veiling of the image from the insolubilizing of the pigmented gelatin. When using an arc or Photoflood lamp, a fan may be used to cool the printing frames.

The sensitiveness of the tissue depends upon (1) the concentration of the sensitizing solution, (2) the age of the tissue, (3) the temperature, (4) the color of the tissue. Other things being equal the time of exposure is less for violet and blue than for black, brown or red tissues.

Bekk—Sensitometry of the Pigment Process. Klimschs Jahrb., **28** (1935), 119.

Boueck—Sensitometry of Bichromate Gelatin. Proc. Ninth Int. Congress of Phot., Paris. 1935. S.&I.P. (II), **6** (1935), 327.

Hardy and Perrin—Sensitometry of the Bichromated Gelatin Process. J. Franklin Inst., **205** (1928), 197–219.

Transfer.—Transfer is necessary because the insoluble pigment which has been formed by the action of light is upon the surface of the tissue while the insoluble pigment which must be washed away in order to reveal the image lies beneath the image. It is, therefore, necessary to transfer the pigment so that the soluble pigment will be on top where it can be washed away without affecting the pigment forming the image.

In single transfer, the exposed tissue is transferred directly to the final support; in double transfer the image is first transferred to a temporary support on which it is developed by washing away the soluble gelatin in warm water. From this temporary support it is transferred a second time to the final support.

We will deal with single transfer first.

The final support may be the gelatin coated transfer paper obtainable from dealers, opal, glass, porcelain or metal. These latter must first be coated with a 3 per cent solution of bichromated gelatin which after drying should be exposed to light for several hours to render the gelatin layer insoluble.

A sheet of single transfer paper is placed in cold water at about 60° F. (16° C.) for several minutes until it is limp. The exposed tissue is then placed in the same water. The tissue will at first curl inward and then outward until it becomes practically flat. At this point it should be removed from the water and placed face down upon the transfer paper, which should have been previously placed upon a flat surface with the side coated with gelatin upwards. When the two are in contact, a squeegee is passed over the same from center to the margin with moderate pressure in order to eliminate air and moisture. After being squeegeed into contact the tissue and its support may be placed under blotters and allowed to remain for fifteen to twenty minutes before development.

Development.—Place the tissue and its support in water at about 95° to 100° F. (35° to 38° C.). In a few seconds the pigment will begin to ooze out around the edges. When this begins, separate the corner of the tissue and its support by lifting it with the finger nail and pull off the paper that originally held the pigmented gelatin. This tissue may be discarded. Holding the print by one corner, gently splash warm water over the surface. The soluble pigment will gradually wash away leaving the image. Care should be taken not to touch the print with the hands or any hard substance as the gelatin is very soft and easily injured at this stage. If the print is under exposed, the pigment will wash away very easily while if exposure is excessive the pigment dissolves with difficulty and warmer water must be used. Highlights may be lightened or detail in dark shadows may be brought out at this stage by squirting water from a blow tube against the print, or hot water may be poured on the desired portion.

If the image is too dark, overexposure is indicated. A light print with clear highlights from which the pigment has completely disappeared indicates underexposure, or developing in water above the proper temperature. Prints which are slightly overexposed may sometimes be improved by raising the temperature of the water during development or by adding a few drops of ammonia or a 2 per cent solution of ammonium persulfate.

When development is complete, place the prints in clean cold water for a minute and then transfer to a five per cent solution of alum to remove the bichromate stain and harden the gelatin. Porcelain steel enamelled or hard rubber trays may be used for the alum solution but tin or zinc vessels, such as may be used for development, are to be avoided. The time required in this bath varies, but sufficient time should be given to make sure that all of the bichromate stain has been removed as any trace which is left will be more noticeable when dry than while wet.

After clearing and hardening in the alum bath, the print is removed and well rinsed in water and then hung up to dry. Carbon prints should not be forced in drying by heat as there is a danger of the gelatin cracking. An electric fan, however, may be used to hasten the process.

Double Transfer.—Before development, instead of being attached to the transfer paper, the exposed carbon tissue is fixed to a temporary support. This temporary support may be opal glass or the specially coated paper supplied by the Autotype Company.

Before use, the support must be waxed so that the gelatin image may be stripped from the temporary support without danger when transferring to the final support. The waxing solution consists of one part of beeswax and three parts of resin dissolved in turpentine and may be purchased especially prepared. Several drops of this waxing solution are poured on the temporary support and gently rubbed over the surface using a pad of flannelette. The waxing is a simple operation but care must be taken that the support is evenly and thoroughly waxed. If a part of the support has not been covered at all the gelatin may adhere and the print will then be spoiled. An hour or so must be allowed after waxing before the supports are used in order to allow the turpentine to evaporate. It is an excellent plan to wax the supports several hours, or on the day before they are to be used.

There is less latitude in development with double than with single transfer and the exposure should be as nearly correct as possible in order that very hot water may not be necessary for development. There is a tendency for the image to blister while on the temporary support which is due to a softening of the wax and the use of hot water, of course, will cause the wax to soften more than cold.

The temporary support is placed in water along with the exposed tissue and allowed to remain until it becomes comparatively flat. The exposed tissue is then squeegeed to the waxed side of the temporary support and allowed to remain under pressure for several minutes after which it is developed in exactly the same way as single transfer. After development, the temporary support with its adhering image is placed in the alum bath to discharge the bichromate stain and harden the gelatin, after which it is rinsed and allowed to dry. Care should be taken not to injure the delicate surface during any of these operations. Dry the image in a cool place—not in the sun nor by any kind of heat.

When dry, the operation of transferring the image to the final support may be proceeded with. For this purpose double transfer paper is supplied in a wide variety of tones and surfaces. The sheet of double transfer paper should be larger than the temporary support, say 7 × 9, for 5 × 7 print. It is placed in cold water and allowed to soak for an hour in order to swell the gelatin coating so that the image will adhere. After soaking for an hour remove and place for a minute or so in water at about 90° F. until the surface feels slimy to the touch after which it is again returned to the cold water where it may remain until required. The dry print on the temporary support is now placed in cold water until flat and limp and is then taken out and placed face up upon a smooth flat surface as a sheet of plate glass. The sheet of softened double transfer paper is then placed on top of it and held in place by one hand while the two are squeegeed into perfect contact with a flat squeegee. The pressure must be sufficient to force out the water but not so great as to affect the gelatin. A few trials will serve to show the proper amount of pressure to apply. The temporary support and double transfer paper are then hung up on a line to dry. When thoroughly dry, insert the point of a knife blade under one corner and pull the two apart, when it will be found that the image leaves the temporary support and adheres to the double transfer paper. If the plate has not been properly waxed, the image may adhere to the temporary support in places and the print ruined. This may also happen if the gelatin coating of the double transfer paper has not been sufficiently softened before use.

The Gum Pigment Process (Gum-Bichromate).—The gum bichromate process is one of several which depend upon the action of light on a bichromated colloid. Unlike carbon and carbro, there is no transfer, and multiple printing is necessary in order to secure a full scale of gradation. As a printing medium the gum-bichromate process is one of the most flexible and is especially noteworthy for its ability to produce deep, rich shadows without any trace of muddiness. It is, however, a rather tedious process and in recent years has been used less and less.

Preparing the Paper.—Rough water color or charcoal papers, depending upon the size of the print and the amount of detail desired, are suitable.

This is coated first with a sizing solution, the following being a suitable formula.

Bermuda arrowroot	90 gr.	18.7 gm.
Water	10 oz.	1000 cc.

Using a little of the water, make a thin cream of the arrowroot. Then heat the remainder of the water to the boiling point and add to the arrowroot mixture. As the solution does not keep it must be made up fresh for each batch of paper sized. The sizing solution is best applied with a Blanchard brush.

After sizing, the paper is coated with a mixture containing pigment of the color desired, gum arabic, and potassium bichromate. The proportions vary with different workers and according to the paper, the negative, and the effect desired. The formulas which follow are due to Paul L. Anderson.

Gum Solution

Water	12 oz.	1000 cc.
Gum-arabic	2200 gr.	336.6 gm.
Arrowroot	270 gr.	44.6 gm.
Mercuric chloride	15 gr.	2.5 gm.

Dissolve the mercuric chloride in a small amount of water and then add the arrowroot, stirring the same until a thin cream is obtained. Then add the remaining water and the gum-arabic. The latter will dissolve more rapidly if suspended in the solution by means of a cheesecloth bag. From sixteen to twenty-four hours will be required for the latter to completely dissolve.

Sensitizing Solution.—The stock solution of sensitizer consists of a solution of potassium bichromate:

Water (hot)	15 oz.	1000 cc.
Potassium bichromate	720 gr.	96 gm.

Both of these solutions keep well.

The actual mixture used for coating varies with the paper and the negative and also with the effect desired. Practically every worker develops a different formula after practice and while there may be little difference, yet it is better adapted to his own personal methods of working.

However, the following formulas are given for the benefit of the beginner:

Shadow Coating

Gum solution	½ oz.	15 gm.
Sensitizer	½ oz.	15 gm.
Ivory black from tube	4 in.	4 in.

If the negative has a short scale of gradation it may be possible to use the above for all the printings; if, however, this is not the case and the negative has a long scale of gradation and prints well with bromide or platinum, then it will be necessary to vary the coating mixture so as to secure a longer scale. It is generally necessary to make three printings; one for the shadows, another for the halftones and finally one for the highlights. The following are advised for the halftone and highlight coating mixtures.

Anderson—The Gum Pigment Process. Amer. Phot., 7 (1913), 504, 584, 648, 700, 707; **8** (1914), 8, 12, 76.

Batty—A Simplified Method of Printing in the Gum-Bichromate Process. Phot. J., **63** (1923), 398.

Grandmaitre—Multi-Layer Gum Process. Bull. Soc. franc. Phot., **10** (1923), 16.

Leighton—A Method of Working the Gum-Bichromate Process. American Annual of Photography (1924), p. 40.

Libby—Multiple Gum. American Annual of Photography (1922), p. 124.

Starnes—The Gum-Bichromate Process and a New Colloid. Phot. J., **58** (1918), 287; Brit. J. Phot., **66** (1919), 50.

Halftone Coating Mixture

Gum solution	½ oz.	15 gm.
Sensitizer	½ oz.	15 gm.
Ivory black from tube	2 in.	2 in.

Highlight Coating Mixture

Gum solution	½ oz.	15 gm.
Sensitizer	5 dr.	17.75 cc.
Ivory black from tube	1 in.	1 in.

Increasing the amount of pigment in the coating mixture results in a longer range of tones, but the whites tend to be degraded.

Increasing the amount of gum arabic results in greater contrast, while an excess produces a thick film which may chip off in development. Increasing the proportion of potassium bichromate results in decreased contrast; an excess produces flat, lifeless prints.

Coating.—The coating mixture having been prepared, the sensitizing of the paper may proceed. Rough papers are the easiest to coat and the beginner is therefore advised to start with rough paper, as Whatman's. The sheet should be larger than the negative as it is next to impossible to secure a perfectly even coating to the very edge of the paper. A sheet 11 × 14 will be suitable for either 8 × 10 or 10 × 12, while an 8 × 10 sheet is sufficiently large for a 5 × 7. Attach the paper to the drawing board with push pins and pour the coating mixture in the center. The paper will be more easily coated if it is immersed in water and blotted before being placed on the board. For the first 11 × 14 sheet of paper, about one half ounce of the coating mixture will be required, while succeeding sheets will require somewhat less, owing to the brushes becoming charged with the gum. The rubberset bristle brush is used to spread the coating over the paper so that every part is covered with the coating mixture. When this has been done, the blender comes into play. There are two brushes which may be used for blending (one made of fitch and the other of badger) and the details of the operation depend somewhat upon which is being used. With the former the brush is held nearly vertical and drawn slowly and regularly across the paper—always in the same direction. When the sheet has been covered in one direction, it is again gone over in the opposite direction, to secure a perfectly even coating. With the latter, the action may be "whippy," the vigorous handling of the brush lessening as the operation proceeds. The exact manner of handling the brush and the time to stop blending will come with a little experience. In general, it may be said that when the point is reached where the tendency of the gum solution is to run into small puddles, the operation should be stopped whether the surface appears completely even or not. Any irregularity will disappear in drying or development or will be covered by subsequent printings. As soon as the operations are complete the utensils should be washed free from the gum solution, as it is very difficult to remove when dry.

The coated paper should be placed in a dark, dry, and dust-free place where there is a good circulation of air to dry. From one to two hours will be required for drying at ordinary room temperature. If it is not to be used at once, the paper should be stored in an air-tight container such as used for carbon tissue. The coating is at its best when fresh.

Exposure and Development.—When exposing by daylight an actinometer of the type used in carbon printing must be employed to determine when the coating has been properly exposed. Artificial lights such as the white flame arc and mercury vapor tubes may be used, and in this case it is sufficient to expose by time. There is a good deal of latitude in exposure, but correct exposure enables water at ordinary temperature to be used for development and produces the best results. Overexposure may be compensated for to a certain extent by raising the temperature or the addition of a few drops of ammonia to the water. An underexposed print is useless as the image washes away in development.

To develop, the exposed print is placed face up in a large tray of clear water at a temperature of about 65° F. When limp it is turned face down, care being taken that no airbells are imprisoned beneath it. From time to time it may be examined and transferred to a tray of clear water. From ½ to 1 hour will be required for the complete development of a properly exposed print. If the image appears fully developed in ten or fifteen minutes the print is underexposed and may as well be thrown away. If the image does not appear in thirty to forty minutes, the print has been overexposed.

When the solution which drains from the print when removed from the water is practically clear, development may be considered complete.

To lighten any local portions the print may be held under water and a stream of water from the tap allowed to fall upon the desired portion, or an atomizer used. Greater emphasis may be secured by using hot water or by holding the print so that the stream of water falls directly upon the surface. Local values may also be lightened by the use of a very soft brush. There is a tendency for brush work to show graininess and for that reason it should be avoided whenever possible.

If it is desired to darken any part, the coating mixture may be prepared and applied by means of a brush to the desired portions and the whole exposed to light when dry. It is then washed in water for about half an hour and dried in the regular way. It is necessary to include the sensitizer in order to secure the same tone as the original deposit.

Multiple Printing.—Gum-bichromate is a short scale process and to render a full scale of tones, or to obtain the rich luminous shadows which are characteristic of the process, multiple printing must be resorted to. Usually the result desired may be obtained in 3 printings, one for the highlights, one for the middle tones, and one for the shadows; but at times 4 or 5 printings may be necessary. The proportions of gum and pigment and sensitizer in the coating mixture vary for the different printings as shown in the formulas on p. 482.

It is necessary in multiple printing to provide means for ensuring the accurate superimposition of the images produced by the different printings. Many methods have been devised for this purpose.[7]

Perhaps as satisfactory a method as any is to use a printing frame several sizes larger than the negative. The negative is attached to the glass, and near the middle along each side is placed a strip of white paper. Prior to the first printing the coated paper is placed in posi-

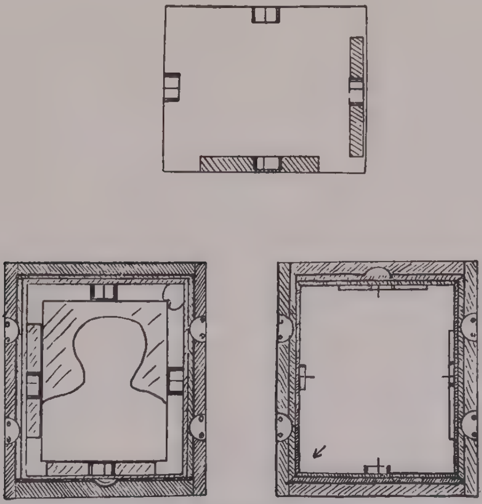

FIG. 208. Zerbe's Method of Registration

[7] Owen, *Amer. Phot.* (1923), 416. Zerbe, *Amer. Annual* (1923).

tion over the negative and registration marks placed on each of the four sides as shown in Fig. 208. In this way any shrinkage which may take place between printings is distributed from the center.

Gum Bromide and Gum Platinum.—To avoid the difficulties of multiple printing many workers have combined gum printing with bromide or platinum, using a print made by one of these processes as a foundation to supply the necessary depth to the shadows and middle tones and a superimposed gum pigment image to secure the characteristic appearance of a gum pigment print.

Gum Bromide. A matte or rough matte surface is the easiest to coat. No sizing is needed except with harder papers.

Before exposure the bromide or platinum paper, as the case may be, is placed upon the negative and its position registered by any of the means already considered. It is then exposed and developed in the usual way, to produce an image of the required intensity.

When dry the print is ready for the gum pigment coating. The proportions of gum and pigment in the coating mixture depend upon the depth of the foundation print and the effect desired. The gum pigment coating is dried, exposed, and developed in precisely the same way as a gum-pigment print.[8]

Miscellaneous Pigment Processes.—*Glue Printing:* This is a modification of the gum pigment process developed by Heinrich Kuehn.[9]

Paper is coated with ordinary glue and a suitable pigment. After having been sensitized in a solution of potassium bichromate the paper base is rendered transparent with paraffin oil or kerosene and the exposure made through the paper. The image is developed as in the gum pigment process.

Fresson. This non-transfer process of pigment printing was of Belgian origin and has attracted but a small following. A special gum pigment paper is sensitized with a solution of potassium bichromate and exposed by daylight or strong artificial light. After exposure, the print is placed in a tray of cold water and the temperature gradually raised to approximately 85° F. After three or four minutes immersion the pigmented layer becomes "tacky" in places and the print is removed and placed on a sheet of heavy glass. Water containing finely ground sawdust is then poured over it. The gentle abrasive action of the sawdust removes the softened pigment and gradually brings out the image. The image has a pronounced grain or texture which, however, is not displeasing with certain subjects.[10]

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[8] Davis, "Gum Bromide Printing," *Amer. Phot.* (1921), **15**, 53. Zerbe, "Gum Platinum," *Amer. Phot.* (April 1910).

[9] Kuehn, *Technik der Lichtbilderi,* Innsbruck (1921), 39. Richter, "The Glue Print," *Amer. Phot.*, **17** (1923), 38.

Resinopigmentype. In this pigment process, developed by Prof. Rudolph Namias, of Milan, a gelatin coated paper is sensitized in potassium or ammonium bichromate, dried and exposed under a positive transparency. It is then placed in cold water for several hours to eliminate the excess bichromate and transferred to water at 50° C. (122° F.) to produce a relief image in differentially hardened gelatin. A resinous pigment, impervious to water (as gum dammar shellac, bitumen or dragons blood with a suitable pigment) is then applied with a brush. The pigment adheres to the swollen portions of the image (after the surface moisture is removed) but not to the hardened portions, thus forming a pigment image.[11]

Sury's Process.[12] J. Sury, of Belgium, patented in 1914 a powder process in which paper was coated with gelatin, gum arabic, or albumen to which was added a fine colorless powder to produce an inert and matte surface. The paper was sensitized in a bichromate, dried and exposed under the negative to daylight or strong artificial light. After exposure the paper was washed in water to remove the soluble portions of the colloid and dried. Finally, pastel colors were applied, the powder added to the colloid coating providing a " tooth " and the image worked up. The process attracted only a small following and the paper is no longer available commercially.

Powder Processes. Practically none of the processes described in the older works on photography have survived nor is there much interest in the subject today. It may be useful, however, to call attention to the fact that a developed silver image, such as a bromide print, may be converted into one which will accept an inert pigment by bleaching in ferric chloride and tartaric acid,[13] ammonium persulfate, and peroxide.[14] Wall recommended the following process [15]

The bromide print, which should have been fixed in plain hypo and not in an acid fixing and hardening bath, is transferred directly from the last wash water to the following solution:

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[10] Mauret, *Amer. Annual of Phot.,* **43** (1929), 179.

[11] Namias, B.P. 205,092 of 1922, *Brit. J. Phot.,* **72** (1925).

[12] B.P. 21,958; *Brit. J. Phot.,* 61 (1914), 748.

[13] Capstaff, U.S.P. 1,315,464 (1919).

[14] Liesigang, *Phot. Archiv.,* **39** (1897), 161. Andresen, D.R.P. 103,516 (1898).

[15] *Amer. Phot.* (1924), 428.

Cupric sulfate	28	gr.	5	gm.
Nitric acid	45	min.	6	cc.
Potassium bromide	4	gr.	0.5	gm.
Hydrogen peroxide	1⅗	fl. oz.	100	cc.
Water to make	16	oz.	1000	cc.

which should be used at a temperature of 70° F. (21° C.). The duration of the action ranges from 5–20 minutes, being dependent probably on the emulsion.

For the powdering of the image any inert pigment, black or colored, may be used, but it should be as finely ground as possible, or the results may show an undesirable amount of grain. The powder may be applied either with a very soft brush or by means of a little sieve having a bottom of the finest muslin. Some of the powder is placed in the sieve which is held over the image and tapped with the finger. This method is perhaps preferable when using a pigment containing rather coarse particles.

CHAPTER XXV

PRINTING PROCESSES: CARBRO AND BROMOIL

Chemistry of Processes Based upon the Insolubilization of Bichromated Colloids by Finely Divided Silver.—Carbro and bromoil are the most important of a number of printing processes, based upon the discovery by Howard Farmer, in 1889, that in the presence of gelatin, the bichromates are reduced by finely divided silver so that when a bromide print is immersed in a solution of bichromate, the gelatin in contact with the silver image is rendered insoluble without exposure to light.[1]

In the carbro process (carbon from bromide prints) the carbon tissue is sensitized by immersion in a solution of potassium ferricyanide, potassium bichromate and potassium bromide. The tissue is then placed in contact with the wet bromide print. While the two are in contact certain chemical reactions take place which produce an image in the carbon tissue similar to that formed upon exposure to light under a negative. The carbon tissue after having been transferred to a suitable support is developed as in the carbon process. The carbro process thus provides a means of making carbon prints from a bromide print, utilizing the finely divided silver of the bromide print rather than light as the means of differentially hardening the gelatin.

[1] B.P. 17,773 of 1889.

Bullock—Theory of the Carbro Process. Phot. J., 67 (1927), 213.

Murray and Spencer—The Hardening of Gelatine by Means of Copper-Dichromate Solutions. Phot. J., 73 (1933), 497.

Lighton—Theory and Practice of the Carbro Process. Phot. J., 67 (1927), 362–372, 409–420.

Schiel—Bromoil Printing. Phot. Rund., 63 (1926), 55–58, 97–99, 182–186.

Schiel—Chromic Acid Bleach and its Reaction Product. Phot. Korr., 63 (1927), 117–120.

Schrommer—Gelatin Hardening in Chromate Processes. Phot. Rund., 63 (1926), 120–122, 138–141.

Tritton—Theory of the Carbro Process. Phot. J., 66 (1926), 126–133.

Venn—Further Researches in the Bromoil Process. Brit. J. Phot., 73 (1926), 384–386, 401–404.

In the bromoil process, a bromide print is bleached in a solution containing a bichromate, or chromic acid, potassium bromide and either potassium ferricyanide or a cupric salt, usually the chloride or the sulfate, which results in the tanning of the gelatin in contact with the grains of silver, thus producing an image in differentially hardened gelatin. The bromide print is then soaked in water which is repelled by the unhardened gelatin. An oil pigment is then applied with a brush. The pigment adheres to shadow portions of the image but is repelled by the highlights which are more or less saturated with water. Thus there is built up a pigment image on one of differentially hardened gelatin.

From a chemical standpoint the two processes are essentially the same; the mechanism of the two processes, however, is somewhat different, as in bromoil the insolubilization of the gelatin takes place in the film containing the image, while in the carbro process the insolubilization has to be produced in another layer of gelatin by diffusion.

The probable reaction here is first the bleaching of the silver image, resulting in the formation of silver bromide and potassium ferrocyanide. This is reoxidized by the bichromate back to ferricyanide, the reduction of the bichromate resulting in the insolubilization of the gelatin. With copper salts the reaction is essentially the same, the cupric salt and bromide reacting with the silver image to form cuprous bromide, which is reoxidized by the bichromate into a cupric salt, the reduction of the bichromate resulting in the insolubilization of the gelatin. Hypothetical reactions can, and have been, written to represent these reactions but the objection to all such equations is that while they show what can take place, there is little evidence to show that it does take place. Consequently, it does not seem worth while, at the present time, to attempt to represent the reaction in the form of a chemical equation.[2]

The Carbro Process.—Any standard make of smooth or semi-matte bromide paper is suitable, for the bromide print, although one without a super coating (non-abrasion) is preferable. The super coating occasionally results in granularity and a loss in the highlights. Some improvement may be effected by making the print darker.

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[2] Namias, *Phot. Jl.*, **42** (1912), 57; *Brit. J. Phot.*, **59** (1912), 217. Eder, *Handbuch*, **4** (1917), 279. Venn, *Brit. J. Phot.*, **71** (1924), 427; **72** (1925), 119. Lighton, *Phot. Jl.*, **66** (1926), 545; **67** (1927), 362. Tritton, *Phot. Jl.*, **66** (1926), 126. Schömmer, *Phot. Rund.*, **63** (1926), 120, 138. Schiel, *Phot. Rund.*, **63** (1926), 55, 97. Schrott, Bromoil Printing and Transfer by Mayer, American Photographic Publishing Co., Boston. Murray and Spencer, *Phot. Jl.*, **73** (1933), 497. Bullock, *Brit. J. Phot.*, **70** (1923), 491. Van Kleef, *Zeit. Wiss. Phot.*, **8** ( ), 435.

If developing-out papers of silver chloride are used, the print should be made darker than would be necessary for a bromide print, and before use, it should be bleached in the usual ferricyanide-bromide solution as used for sepia toning (p. 442) and redeveloped in an ordinary developer.

The print, whether on a bromide or a chloride paper, should receive full exposure and development. A slight burying of the gradations in the shadows is not objectionable as these gradations will be retained in the pigment image.

Where the water supply contains lime, it is well to place the print, after fixing and washing, in a solution of hydrochloric acid and water (3 parts concentrated hydrochloric acid to 100 parts of water) for 5 minutes, then wash for ten minutes. If this is not done there is a danger that the lime formed within the bromide print will prevent complete bleaching of the highlights with the result that they wash away in the development of the carbro.

Should any spotting be required, or it is desired to darken certain portions in such a way that the result will be reproduced in the carbro print, one may use water color containing India ink. All such alterations are reproduced in the carbro print with as complete transference as any part of the image.

Sensitizing the Carbro Tissue.—For this purpose the following stock solutions are required:

Concentrated Solution No. 1:		
Potassium bichromate	1 oz.	10 gm.
Potassium ferricyanide	1 oz.	10 gm.
Potassium bromide	1 oz.	10 gm.
Water to make	20 oz.	200 cc.
Concentrated Solution No. 2:		
Glacial acetic acid	1 oz.	10 cc.
Hydrochloric acid (pure)	1 oz.	10 cc.
Formaldehyde 40 per cent	22 oz.	220 cc.

Braham—The Carbro Process. Phot. J., **62** (1922), 16; Brit. J. Phot., **69** (1922), 4.

Farmer—The Carbro Process. Amat. Phot. (1919), p. 285; Brit. J. Phot., **66** (1919), 583; Amer. Phot., **14** (1920), 92.

Garon—Revised Formulae for Carbro. Brit. J. Phot., **68** (1921), 327.

Lighton—Sharpness of Reproduction in the Carbro Process. Phot. J., **66** (1926), 545-551.

The addition of 1¼ oz. or 12 cc. of water to the above will prevent precipitation in cold weather.

For use take:

First Bath:		
Concentrated No. 1 stock solution......	6 oz.	100 cc.
Water to make......................	18 oz.	300 cc.
Second Bath:		
Concentrated No. 2 stock solution......	1 oz.	10 cc.
Water to make......................	32 oz.	320 cc.

The above English and metric weights are not equivalent but are proportionate.

The first bath may be used for a number of prints, but the second bath is affected by the number one bath carried over into it with the pigmented tissue so that it must be renewed frequently.

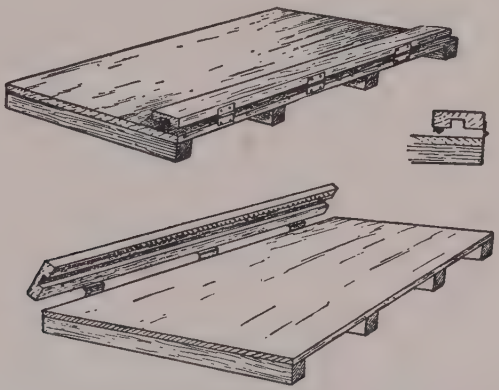
The first and second baths should be as near the same temperature as possible and not colder than 60° F. nor warmer than 70° F. (15°–20° C.). A low temperature results in light prints lacking in contrast and a high temperature in dark prints with clogged shadows.

The working baths having been made up, the sheet of carbon tissue is immersed in No. 1 bath by sliding it under the surface of the solution. Remove any air-bells on the face of the tissue and then turn it face downwards. After two minutes the pigmented tissue should be again turned face upwards and allowed to remain for another minute. Then lift it up by the corner and let it drain for 15 seconds. Finally grasp it by two corners and slide it face up into solution No. 2.

The time of immersion controls the depth and contrast of the carbro print and the correct time in the second bath depends upon the degree of contrast required, the brand of paper employed for the print, the degree of contrast of the print, the hardness of the water, and, to a minor degree, by the number of carbro prints which have been made from the print. The shorter the time of immersion the greater the contrast of the carbro print; increasing the time in the second bath results in less contrast. Prolonged immersion produces a pale and flat carbro print; a short time results in a dense print lacking detail in the highlights which in extreme cases may wash away entirely.

The normal time is from 20 to 30 seconds. If the water supply is very soft the time of immersion is less and under such circumstances the solution may be diluted with one-half the total quantity of water.

Making the Print.—The number of seconds decided upon having elapsed, the pigmented tissue is lifted from the bath and laid upon the bromide print which should have been previously soaked in water for ½ hour and laid upon a sheet of glass or upon the squeegee board illustrated in Fig. 209. Once the two are in contact their relative positions must on no account be altered as the action begins immediately and a change in position would produce a blurring of the image. As soon as the pigmented sheet is in contact with the bromide print a rubber squeegee is brought into play and the superfluous water forced out by firm, straight strokes.



The upper drawing shows the hinging of the clamping strip at the requisite height above the base. In the lower drawing is indicated the edging of studded rubber.

FIG. 209. Squeegee Board for Carbro (Farmer)

The bromide print with its adhering sheet of carbon tissue is then lifted from the glass or squeegee board, placed between greaseproof paper and allowed to remain for 15 minutes for the action of the insolubilizing solution to take place.

The proper amount of pressure in squeegeeing is a matter of importance. If the bromide print and the pigmented tissue adhere tightly and force is required to separate them, the pressure has been too great; on the other hand if they tend to separate of their own weight, greater pressure should be applied. Lack of sufficient pressure leads to light carbro prints.

Transfer.—The sheet of transfer paper, which has been soaking in water for at least 15 minutes, is now placed on a sheet of heavy glass, laid flat on the working table, a glass of water poured over it so as to leave a pool of water on the surface. The pigmented tissue is now stripped from the bromide print, squeegeed into contact with the tissue, and placed between blotters under light pressure for 20–30 minutes. Heavy pressure leads to difficulty in developing. The longer the time elapsing before developing, the darker the carbro print, as the action continues.

Developing the Carbro.—The carbro print is developed in the same manner as a carbon print (which see) but with water at a lower temperature (95°–100° F., 35°–38° C.) as the soluble gelatin leaves the tissue at a lower temperature and more readily than with a carbon print made in the usual way by exposure beneath a negative.

When development is judged to be complete, the print is removed, raised in clear cold water and placed in a 5 per cent solution of alum. This removes the yellow stain left behind by the bichromate and ferricyanide and hardens the image. Care should be taken that the action of the alum is complete as the yellow stain is much more apparent when the print is dry than when wet. In commercial practice it is well to use two baths of alum; immersing the print until apparently clear in the first, then transferring to the second for 3 or 4 minutes.

After removal from the alum bath the print should be rinsed well in cold water and hung up to dry. Heat should not be used to hasten drying.

Treatment of the Bromide Print.—Wash the bleached bromide print in water for 15 to 20 minutes and redevelop in the usual developer. Development must be complete. Fixing is unnecessary; after development wash the print for 10–15 minutes in running water and dry. When dry it is again ready for use. Succeeding carbro prints will be darker and have greater contrast than the first. This may be overcome by increasing slightly the time of impression in the No. 2 bath.

Carbon on Bromide.—If desired the pigment image can be developed on the bromide print instead of transferring to a new paper support. The procedure is just the same except that when the fifteen minutes of contact between the bromide and the pigmented tissue have elapsed, instead of stripping off the pigmented paper, both it and the bromide print are placed in warm water and developed as already described. The print then consists of a pigment image over the bleached image of the bromide print. This last may be allowed to remain, redeveloped or removed by means of the ordinary ferricyanide-hypo reducer.

As the yellow color of the bleached image alters the tone of the finished print and since it darkens slightly on exposure to light it is advisable either to redevelop the bromide image or to remove it completely. Redevelopment of the silver image darkens the print since in this case the resulting print has the depth of the two images; one of silver and the other of carbon. This property may be used to advantage in dealing with weak negatives from which it is impossible to get sufficient richness in the ordinary way.

Causes of Failure.—

White Spots: Bubbles or airbells adhering to the tissue during sensitizing or to air being imprisoned between the bromide print and the sensitized tissue. White spots on the carbro are always accompanied by corresponding dark, or unbleached, spots on the bleached bromide.

Dark Spots: Dark spots on the carbro are due to insufficiently washed prints.

Frilling at the Edge: Lack of a safe edge, i.e., white margin on the bromide print.
Bad movement during squeegeeing.

Blisters: Air trapped between the pigment paper and the transfer paper.

The Carbro is Devoid of Highlight Tones: This is due to an excess of lime or chalk in the water used for washing the bromide print. The remedy is to place the bromide print for 5 minutes in a solution of hydrochloric acid (three parts acid to 100 parts of water) and wash for ten to twenty minutes in running water. Insufficient immersion in the No. 2 bath.

Light Prints Lacking in Contrast: Weak squeegeeing. Prolonged immersion in the No. 2 solution.

Dark Prints, With Strong Contrast: Insufficient immersion in the No. 2 bath.

Double Image: Shift in the tissue or transfer paper when squeegeeing.

Bromoil.—The bromoil process, in brief, consists in making a good bromide print in the ordinary way, bleaching this in a solution which produces an image in differentially hardened gelatin, and finally applying pigment with a brush to form an image. Owing to the fact that an ordinary bromide print is used, neither daylight nor an enlarged negative is necessary.

The Choice of the Paper for the Bromide Print.—To be suitable for the bromoil process, the bromide paper should have a hard, durable, and well-sized paper base, with an emulsion rich in silver and thickly coated. No hardening substances should be added to the emulsion in the course of manufacture nor should the paper have a super-coating. The bromoil process is based upon tanning of the gelatin in exact proportion to the original silver deposit. If the emulsion has been hardened in manufacture, the gelatin is already tanned to some extent and has lost much of its swelling power, so that it is difficult to obtain the degree of relief necessary for pigmenting.

A number of manufacturers supply bromide papers especially designed for bromoil, and for the beginner these are to be preferred.

To determine whether a particular brand of paper is suitable for bromoil, an unexposed sheet should be dipped in water at a temperature of 86° F. (30° C.) and the behavior of the gelatin observed. If this swells up considerably and becomes slippery and shiny, the paper has the necessary swelling power and can be used for bromoil.[3]

The Bromide Print.—The best bromide print for the bromoil process is one which has received correct exposure and development for a period slightly less than that required for full depth. The shadows should be a deep gray and not the maximum black which the paper will produce. The highlights, on the other hand, should be a trifle darker than would be considered proper for a bromide print. If the factorial method of development is employed, the factor normally employed should be reduced by approximately one-third. Diaminophenol, which is without tanning action on gelatin, is widely used as a developer but metol-hydroquinone may be used. In either case the solution should be fresh, as the oxidation product present in a used developer may result in partial tanning of the gelatin.

The print should be fixed in plain hypo solution or in one made acid by the addition of sodium bisulfite. An acid fixing and hardening bath is to be avoided as, owing to its hardening action, considerable difficulty is experienced in securing the necessary relief.

After fixing, the prints should be thoroughly washed as the slightest trace of hypo will cause trouble in bleaching.

The prints should have a plain white margin of at least one-half inch.

Bleaching Bromide Prints.—The functions of a bleaching solution are two in number: (1) it removes the visible silver image and (2) produces a tanning of the gelatin film in proportion to the amount of silver present in the image.

The usual bleaching solution contains a bichromate (potassium bichromate) or chromic acid, potassium bromide, or sodium chloride, and a cupric salt, usually either the chloride or the sulfate.

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[3] Mayer, *Bromoil Printing and Transfer,* American Photographic Pub. Co., Boston.

Bleaching and tanning may be carried out simultaneously in a single bath or separately in two baths. Of the many formulas for combined bleaching and tanning solutions, two must suffice.

(1) *A.*	Copper sulfate	¾ oz.	200 gm.
	Water to	3½ oz.	1000 ccs.
B.	Potassium bromide	¾ oz.	200 gm.
	Water to	3½ oz.	1000 ccs.
C.	Potassium bichromate	150 gr.	10 gm.
	Water to	3½ oz.	1000 ccs.[4]

For use take:

A	2 oz.	60 cc.
B	2 oz.	60 cc.
C	⅔ oz.	20 cc.
Water to	15 ozs.	450 ccs.
Hydrochloric acid (conc.)	15 drops	

(2)	Copper sulfate (10% solution)	96 cc.
	Potassium bromide (10% solution)	73 cc.
	Chromic acid (1% solution)	27 cc.
	Water to make	1000 cc.[5]

The following formulas for bleaching and tanning in separate operations are due to Venn.[6]

Bleaching Solution (*No. 1*)	
Cupric sulfate (10% solution)	95 parts
Potassium bromide (10% solution)	5 parts
Tanning Solution (*No. 2*)	
Potassium bromide (10% solution)	20 parts
Potassium bichromate (1% solution)	10 parts
Water to make	100 parts

The first bath may be used for a number of prints in succession; the second should be renewed more frequently.

The temperature of the bleaching and tanning solutions should be uniform and between 55° and 65° F.

Approximately five minutes will be required in the second bath, after which the prints should be washed thoroughly in running water, and then fixed for two minutes in a 10 per cent solution of hypo. If the print is not washed thoroughly before being placed in the fixing bath, general tanning will be produced through the interaction of the hypc and the substances remaining in the print from the tanning solution. An acid fixing and hardening bath must not be used for fixing.

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[4] Mayer, *Bromoil and Bromoil Transfer.*

[5] Crowther, *Amateur Photography,* 1921, 446.

[6] *Brit. J. Phot.,* 71 (1924), 427.

After fixing, the print should be washed in running water for 5 to 10 minutes and dried. Some papers do not need to be dried at this stage but it is usually advisable.

Producing the Relief.—When ready to begin pigmenting, the print is immersed in water and the gelatin allowed to swell. The degree of swelling is controlled principally by the temperature of the water and, to a lesser extent, by the time of immersion. The higher the temperature of the water in which the print is soaked, the greater the swelling and the more pronounced the relief. With insufficient immersion, or the use of cold water, the degree of swelling will be insufficient and such prints will, when pigmented, have a short scale of gradation with poor tones. The use of excessively warm water, on the other hand, will produce a pronounced relief which, when inked up, may produce a result having greater contrast than is desirable.

If the degree of relief is correct, the print will accept the pigment from the brush readily and in doing so will differentiate between the highlights and the shadows. After bleaching and washing, the white margins should be very slippery to the touch. If the print is held up by one corner, the straight edge on the margin should be plainly visible.

To determine whether the print is in the proper condition for pigmenting, Dr. E. Mayer suggests that the tip of the finger be passed over the surface gently. With a print in the proper condition the deep shadow portions will feel like very fine sandpaper, that is, grainy and slippery, jelly-like in the highlights, and particularly so along the clear margins.

Water too warm causes over-swelling and the highlights do not take the ink.

The vital factor in putting the print in shape for pigmenting is the adjustment of the swelling of the gelatin to the viscosity of the pigment. Either the print may be soaked at a fixed temperature and the consistency of the pigment adjusted to suit the degree of swelling, or the degree of swelling is adjusted by variation in temperature of the water bath in which the relief is raised to suit the pigment as supplied.

Different papers vary as regards the temperature necessary for producing the best relief. Some are ready for pigmenting after soaking for several minutes in water at ordinary room temperature. Others require as high as 90° F. (32° C.) or more; the general average being about 75°–80° F. (24°–27° C.). The worker must learn by experience the temperature to use for his particular brand of paper and manner of working, always remembering that it is best to start with a rather low degree of relief, which may be raised easily, if required, by soaking in warmer water, while a relief once too high can be reduced only with difficulty. Should soaking in warm water at a temperature of 95° F. (35° C.) be insufficient to produce the desired degree of relief, the print may be immersed in a 1 per cent solution of sodium carbonate as recommended by E. Guttmann. As a rule, however, this method should be used only as the last resort.

Pigmenting.—The brushes employed for applying the pigment are especially made for the process and may be obtained from dealers. They are made of fitch hair and the end is cut at an angle as shown in Fig. 210. To begin with, three brushes will serve, numbers 10 and 14 and a smaller one for detail work. As the worker progresses, additional brushes will be found convenient in order that a fresh brush may be used when it is necessary to apply pigments of different consistency to any part of the print.

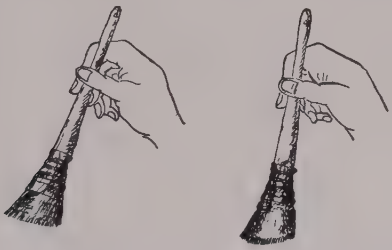

FIG. 210. Proper Position of the Brush in Pigmenting (Mortimer and Coulthurst, *The Oil and Bromoil Processes*)

Brushes should be kept in good condition, not only because they are expensive, but because the quality of the work depends to a large extent upon their condition. After use, the brush should be thoroughly cleaned with gasoline, carbona, or a similar solvent and washed in soap and water until free of both solvent and pigment. Take care not to get the brushes out of shape while cleaning, and when they are thoroughly cleaned, wrap in a piece of white paper and place a rubber band around the handle in order to keep the brush in its proper shape.

The thick, greasy inks used for pigmenting are similar to those used for lithography and are obtainable in various colors and degrees of consistency. The Sinclair "Permanent" Pigment as well as the Drem Pigments of Dr. E. Mayer may be recommended.

It is necessary to keep the print wet from underneath during pigmenting and for this a pigmenting pad is used. Pads are a commercial article and may be obtained from any of the dealers carrying oil materials or one may be improvised from a sheet of glass and four or five sheets of blotting paper. Soak each sheet of blotting paper in water until thoroughly wet and then place on top of one another upon the glass plate. Upon this spread one or two thicknesses of muslin or cheesecloth. Then remove the print from the wash water and place on top of the pad. With a blotter or piece of silk take off the excess moisture, being careful not to make the surface wholly dry. Only take off the excess water. It will be noticed that the image stands out in relief and the appearance of the print at this stage is a good indication of the way it will take the pigment. The greater the relief the more readily the ink will take.

Squeeze out a very small quantity of pigment on the palette. Only a small quantity is needed, as a piece the size of a pea will do for several 8 × 10 prints. Instead of a palette the glass side of an old negative may be used. Spread the pigment out in a thin layer with the palette knife and tap the brush on the same so as to take up the pigment on the end of the hairs. When the brush has become charged with the pigment, work it around on a clear portion of the glass in order to distribute the pigment evenly. It is well to prepare pigments of two consistencies at the beginning, since it is rare that the same pigment can be used throughout the operation owing to the fact that some parts of the image require a softer pigment in order to make the pigment adhere. Either linseed oil, Robertson's medium or megilip may be used to soften the hard ink. Only a trace of any one of these is necessary to completely change the ink and, therefore, they should be added with caution.

The method in which the brush is used to apply the pigment varies greatly with different workers. Some have a pressing, smudging action, while others simply dab the brush on the surface. It is difficult to give any precise directions on this point and with practice one will develop a distinctive method of his own.

It is well to begin pigmenting with the ink as it comes from the tube and continue until the image is distinct and the shadows well defined when it may be desirable to change to a softer pigment. It is easy to tell when more pigment is needed, for the brush will begin to pick up the pigment instead of depositing it.

To lighten any portions which have been over-pigmented, the operation known as hopping is used. In this, the brush is held vertically and allowed to drop upon the surface from which the pigment is to be removed. Wire holders are supplied to hold the brush so that hopping may be carried on without fatigue.

Do not be afraid to apply plenty of pigment, but do not try to put it all on at once. Smooth it down to an even tint on the palette and take up a little on the brush at a time. When this is exhausted, take up more. A smooth, even tone will result if plenty of pigment is used and thoroughly worked into the surface. If the pigment is not well worked in, the print will be weak and "gritty" and the tone will be impure.

All detail which is to appear in the finished print should be apparent after the first inking. If parts of the image are inked strongly before the desired details appear, it is difficult to ink these later.

Particular care is necessary, especially in the case of large prints, or where a long time is required for pigmenting to keep the paper thoroughly wet. To this end it is well to soak the print in water frequently during pigmenting.[7]

Troubles in Pigmenting.—

Highlight areas repell soft ink.

Excessively swollen prints. There is no remedy.

Print refuses to accept ink.

Paper is not suitable for the process, bleaching solution incorrectly prepared. There is no remedy.

Print inks up as a negative.

The ink is too soft. Clean up and apply harder ink.

Print accepts ink but more or less evenly.

Insufficient swelling. Use a warmer water bath for soaking.

Spots appear attracting more ink than the surrounding areas.

Insufficient swelling in spots due to air bubbles or fault of bleaching from the presence of hypo in the bromide print.

Small white spots which refuse to take the ink.

Drops of water on the surface. If the spots move with the brush, the water is on the brush.[8]

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[7] Grimwood, *Brit. J. Phot.*, **72** (1925), 320. Usher, *Brit. J. Phot.*, **75** (1927), 191. Fiedler, *Photofreunde*, **4** (1924), 13. Namias, *Brit. J. Phot.*, **61** (1914), 626. Gabriel, *Brit. J. Phot.*, **76** (1929), 543, 559.

[8] Mayer, *Amer. Phot.* (1925), 506.

Bromoil Transfer.—Bromoil transfer, as its name indicates, consists in transferring the pigment from the bromoil print to a piece of plain paper. As the oily pigment lies on top of a more or less tanned and swollen gelatin it will leave the bromoil print and adhere to a piece of moist paper when the two are brought together under pressure. Transfers, accordingly, have a distinctive appearance which is unlike other pigment processes since in these the image forming pigment is either incorporated in or lies over a colloid layer, while in transfer the pigment lies on a plain uncoated paper.

Preparation of the Bromoil for Transfer.—Any bromide paper which is suitable for the bromoil process may be used for the bromoil prints from which a transfer is to be made.

Bromide papers having a super coating (that is, a second gelatin layer to protect the emulsion and prevent abrasion markings) may be used under certain conditions.[9]

To obtain a transfer of good quality soft ink must be used in pigmenting the bromoil as it is impossible to transfer hard ink with certainty, owing to the tenacity with which it adheres to the original bromoil. Soft ink, however, cannot be used unless a high relief is obtained or the ink will adhere to the highlights of the bromoil and a print of the proper gradation cannot be obtained. Consequently it is necessary to start with a rather high relief; this fact must be borne in mind when the print is being made ready for pigmenting and the temperature of the water in which the swelling takes place regulated accordingly. The use of a high temperature, however, may cause the gelatin in the highlights to soften to such an extent that it pulls off in pigmenting or in transfer. When this occurs it is well to make use of ammonia as previously described. As the ink is more easily transferred from the highlights than from the shadows, in consequence of the greater relief of the former and the fact that owing to the tanning of the gelatin the pigment in the shadows is more strongly retained than in the highlights, the contrast of the transfer is usually much less than that of the bromoil. In pigmenting, therefore, the bromoil is made considerably more contrasty than would be required where it to be left as it is. Owing to the fact that the transfer of ink in the shadows may not be complete, it is the practice of many workers to considerably over ink such portions in order that the transfer may have the proper depth in the shadows. To reach the same end other workers have recourse to multiple transfer; the first bromoil being inked normally and transferred, then reinked, paying especial attention to the shadows.

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[9] Symes, *Brit. J. Phot.*, 70 (1923), 103.

Transfer Papers.—The best papers for transfer are those used for copper plate printing, but water color and drawing papers of good quality are suitable as a rule. Very rough or absorbent papers may require sizing to keep the pigment on the surface of the paper. A 2 per cent solution of arrowroot may be used for this purpose.

As a general rule, the transfer paper should be used dry. Some few papers, however, must be slightly damp. In this case two sheets of blotting paper should be thoroughly and evenly dampened and the sheet of transfer paper placed between them, under slight pressure, for several minutes. As different papers require different treatment, one should use a particular paper until thoroughly familiar with its characteristics.

As a general rule, the more absorbent the paper the better the transfer of pigment. If the paper is too wet the pigment transfers with difficulty, or not at all, and the transfer is smeary. The proper condition is very important and must be learned by experience.

Transfer of the Pigment Image.—A number of presses, similar to those used by copper plate printers, are available commercially.[10]

The primary requirements of a satisfactory press are two in number: (1) The pressure on the rolls must be absolutely even and capable of regulation by the operator, and (2) one must be able to examine the condition of the transfer at any time without danger of shifting the position of the bromoil or the transfer.

As soon as pigmenting is complete the bromoil is ready for the transfer. For this purpose we require, in addition to a suitable press, two sheets of blotting paper, three sheets of thick, hard, glazed pasteboard and a pad of felt—all of which should be at least double the length of the bromoil print. On one of the sheets of pasteboard is placed one of the sheets of blotting paper and on this the pigmented bromoil, face up. Over this is placed the transfer paper, and over this another sheet of blotting paper. These two sheets of blotting paper serve the purpose of absorbing the moisture squeezed from the bromoil print which might otherwise cause trouble. Finally a sheet of pasteboard is placed over the blotting paper, then over this the felt pad and lastly another sheet of pasteboard.

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[10] As for example, those of the Autotype Company, Sinclair, Drem, and Partington. See also: Prett, *Brit. J. Phot.*, 70 (1923), 300. Santeul, *Brit. J. Phot.*, 70 (1923), 301.

The entire pack is now inserted between the rollers and carried through once with a uniform motion and with but slight pressure. The pressure is then increased slightly and the pack carried back through the press in the opposite direction. Then the top of the press pack is removed, the cover of the transfer paper raised and the appearance of the transfer examined. If the transfer of ink is only slight, the press pack is replaced and carried through the press again with increased pressure. Then if the shadows still lack intensity registration marks should be made, the bromoil print removed, resoaked in water and the shadows pigmented after which the bromoil is placed on the transfer paper, its position registered, and again passed through the press. The pressure should not in any case be so great that the rolls can be started only by a decided effort; they must always move easily and smoothly. Repeated slow passage of the press pack through moderately tightened rollers is always more advantageous than a single passage under very heavy pressure. With heavy pressure there is likewise the danger of destroying the bromoil, as the gelatin film in its swollen condition may adhere to the transfer paper. This trouble, however, is occasionally met with when using some papers with only a moderate amount of pressure. To prevent this, Dr. Mayer suggests that the transfer paper be sprayed with oil of turpentine by means of an atomizer.

After spraying the sheet is allowed to stand for fifteen or twenty minutes in order that the turpentine may evaporate. This is a certain preventative of sticking, but sufficient time must be allowed for the turpentine to evaporate, or muddy, uneven transfers will result.

Methods of Transfer Without a Press.—If the transfer paper is dampened with a solvent of the oil pigment such as benzene, benzol, or turpentine, only light pressure is required to transfer the pigment from the bromoil to the transfer paper, since the transfer is effected by the action of the solvent and the adhesive power of the paper. Even the light pressure obtainable in a printing frame or light rolling with a print roller is often sufficient.[11]

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[11] Zaepernick, H., *Amer. Phot.* (1924), 732.

CHAPTER XXVI

PRINTING PROCESSES: PLATINOTYPE, IRON AND PLAN-COPYING PROCESSES

Printing Processes Based on Iron Salts.—A number of the organic salts of iron are sensitive to light and a still larger number are sensitive in the presence of organic matter. Several printing processes are based upon the light sensitive iron salts, among them, ferroprussiate (blue print), cyanotype (blue lines on a white background), kallitype, platinotype, and a number of other processes which are now obsolete.

The Platinotype Process.—The Platinotype Process results in an image of pure metallic platinum. As platinum is one of the most stable metals, prints made by the Platinotype Process may be regarded as being as permanent as the paper on which they are made. The pure black image of finely divided particles of platinum has a certain intrinsic quality which is unique and it is very properly regarded as one of the finest processes of photographic printing.

Although some of the salts of platinum are sensitive to light, particularly in the presence of organic matter, the Platinotype Process is an indirect one depending upon the reduction of a ferric salt to the ferrous which, upon being dissolved in an alkaline oxalate, such as potassium oxalate, reduces the platinum salt (potassium chloroplatinite) to the metallic state.

$$Fe_2(C_2O_4)_3 + \text{light} \rightarrow 2Fe(C_2O_4) + 2CO_2,$$
$$6FeC_2O_4 + 3K_2PtCl_4 \rightarrow 2Fe_2(C_2O_4)_3 + Fe_2Cl_6 + 6KCl + 3Pt.^{1}$$

Papers for the Platinotype Process.—Papers for the process are available commercially in a variety of surfaces and in black and sepia or may be prepared. Papers for brown-black and sepia tones are produced by the addition of a salt of mercury, usually mercuric citrate, to the sensitizer. The probable reaction consists in the reduction of

[1] Sheppard, *Photography as a Scientific Implement*, p. 170.

ANDERSON—The Choice of a Printing Paper with Special Reference to Platinum. Amer. Phot., 7 (1913), 336, 384.

the mercuric salt to the mercurous and the formation of a mercuric-platinum complex on development.

The paper is extremely sensitive to moisture and is supplied in sealed metal cans from which it should be removed only immediately before using.

The exposure scale is rather longer than that of developing papers and while some control is possible through modification of the developer, the best results are obtained with a rather brilliant negative possessing somewhat greater contrast than would be considered necessary for developing papers. Clear and brilliant shadow gradation is particularly important.

Exposure.—The paper should be handled only in artificial or very subdued daylight. The negative should be thoroughly dry. When printing by daylight it is well to place a sheet of wax paper or cellophane over the backs to protect the paper from moisture. The image appears as a brownish-gray deposit against the yellow surface of the paper. Experience is required to determine the proper exposure from the appearance of the partially visible image, but generally the exposure is sufficient if full detail can be seen in the shadow portions of the image.

Development.—The following formula is suitable for the development of black paper:

Potassium oxalate..................	5 ounces	335 grams
Hot water to......................	15 "	1000 cc.

Hot water is required for preparing the developer but it should be allowed to cool to 65 degrees F. (20° C.) before use. It may be used over and over, fresh solution being added to maintain the required volume.

The addition of a small quantity of hydrochloric acid results in softer prints while the addition of potassium bichromate increases contrast. In both cases only a very small amount (1 to 2 minims per ounce or 2 to 5 cc. per litre) is required to produce an appreciable effect.

The following developer is recommended for the sepia papers:

Black developer.....................	10 ounces	1000 cc.
Oxalic acid (saturated solution).......	1 ounce	100 cc.

For best results this developer should be used at a temperature of 150° to 160° F.

Trays which are used for the development and clearing of sepia prints should be set aside for that purpose only, and not used for black papers. Neither should the two papers be cleared in the same solution, nor should they be washed together.

Since the image appears almost immediately, the paper must be immersed in the solution in such a manner that it is easily and quickly covered in one sweep. Any air bubbles which appear should be carefully removed with a soft brush or the tip of the finger. With correct exposure, there is no fear of overdevelopment, and after a full minute's immersion the print may be removed and immersed in the clearing bath composed of hydrochloric acid 1 oz., water 50 oz. (20 to 1000 cc.).

After five minutes immersion in this bath the print should be transferred to a second bath of similar composition for five minutes and then to a third for another five minutes, after which it is washed for fifteen or twenty minutes in running water and dried.

Warm Black and Sepia Tones on Black Papers.—Warm black and sepia tone may be obtained on black papers by adding a mercuric salt to the developer but the image consisting of platinum and mercury is not permanent.

The following formula is suitable:

Solution A			
Potassium oxalate	2 ounces	130	grams
Water	14 "	1000	cc.
Solution B			
Potassium citrate	150 grains	21	grams
Citric acid	240 "	35½	"
Mercuric chloride	90 "	13.5	"
Water	14 ounces	1000	cc.

For use, take equal parts of solutions *A* and *B* and use at a temperature of about 100° F.

Increasing the amount of *B* solution results in a warmer color and a lighter image. The proper allowance for this is made in printing.

Prints developed in a solution containing mercury should be cleared in baths of hydrochloric acid of one-fourth normal concentration or the image will be affected.

The Ferroprussiate Process.—This, the familiar blueprint process, is used chiefly for making copies of architects' and machine plans. The relatively short scale of gradation does not lend itself well to ordinary subjects. The paper is coated with ferric ammonium

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WALL—The Iron Salts. A summary of iron printing methods. Amer. Phot., 16 (1922), 677, 766; 17 (1923), 4.

citrate and potassium ferricyanide. The ferric salt is reduced to the ferrous upon exposure and when the print is placed in water, ferro-ferricyanide, or Berlin Blue, is formed as a result of the reaction between the ferrous salt and the ferricyanide.

Blueprint paper is obtainable commercially in a number of different speeds. The paper is extremely sensitive to moisture and should be kept in tightly sealed cans. The paper is exposed either to daylight or to a suitable source of artificial light such as the mercury vapor lamp in frames especially designed for the purpose. Most commercial printing, however, is done with continuous machines of which there are a number of makes. In general, the principle employed is as follows: An endless belt carries the tracing to be printed and a band of paper around a glass surface formed in the shape of a half-cylinder. This cylinder is illuminated from the inside usually with a mercury vapor tube. The paper is washed by jets of water in the same machine and dried between cloth belts passing over a heated drum.

The paper is exposed until the lines of the drawing appear yellow on a bluish-green background. Development is effected by placing the print in a stream of running water for five to ten minutes. Alkaline water should not be used as it results in bleaching of the print.

Prints are usually hung on a line to dry but may be placed on blotters or cloth if the surface moisture is first removed to prevent drying marks from drops of water on the surface.

Preparation of Blueprint Paper.—Blueprint paper is cheap and easily obtainable, however, the following formula may be of interest:

(B. J. Almanac Formula)

A.	Potassium ferricyanide	1200 gr.	250 gm.
	Water	10 oz.	1000 cc.
B.	Ferric ammonium citrate	432 gr.	90 gm.
	Water	10 oz.	1000 cc.

Almost any paper stock may be used except those consisting wholly or in a large part of wood pulp. In general, a smooth matte paper, well sized, is preferable.

A satisfactory means of coating small quantities of paper is to attach a sheet of paper to a board using stainless steel pins and apply the sensitizing solution with a large, flat, rubber-bound brush. A

Stenger—The Blue-Print as a Photographic Copying Process. Phot. Ind., 30 (1932), 461, 487, 498, 525.

Harper and Powell—Photographic Ferro-Prussiate Processes. B.P. 461,893 of 22.8.35. Addn. to B.P. 427,746.

metal-bound brush must not be used. The paper should be coated as evenly and as quickly as possible, going over the surface with a charged brush, first in one direction and then in rapid circular strokes.

Rapid drying is essential. Either an electric fan or a hot-air dryer such as used by hairdressers may be employed. Paper which is allowed to dry under ordinary room conditions possesses poor keeping qualities.

The addition of 0.5 per cent of oxalic results in a more rapid paper which, however, has poorer keeping qualities. The addition of 0.5 per cent solution of potassium bichromate improves the keeping qualities and tends to prevent staining of the white, but reduces sensitiveness.

Cyanotype or Positive Blueprint Process.—This process produces blue lines on a white ground from an ordinary drawing on tracing cloth or paper. The paper is coated with a solution containing ferric chloride and tartaric acid. The ferric salt is reduced to the ferrous upon exposure to light. The application of potassium ferrocyanide as a developer results in the ferrous salt being converted into ferric-ferrocyanide or Berlin Blue. The product resulting from the reaction of the ferric salt and potassium ferrocyanide is colorless and as it is soluble in water, is removed by washing, producing an image of blue lines on a white background or a positive from a positive drawing. It will be observed that the reaction taking place is practically the reverse of those in the ordinary blueprint process.[2]

Positive blueprint paper is available commercially, but is not widely used owing to its poor keeping qualities.

The paper is exposed in the same manner as ordinary blue-print paper until the lines are distinctly visible in a clear yellow color on a bluish-green background.

A 20 per cent solution of potassium ferrocyanide is used for development. As it is essential that none of the developer reach the back of the print, the paper is pinned to a board using pins of stainless steel and the developer applied with a broad rubber-bound brush. Development is rapid, requiring about one minute. Cold water should then be sprayed over the surface of the print to remove the surplus ferrocyanide. After a preliminary washing of 3 to 4 minutes, the print is placed in a 10 per cent solution of hydrochloric acid for 1 or 2 minutes, then transferred to a second bath of the same composition, where it may be allowed to remain for 4 to 5 minutes and is then washed for several minutes in running water and dried.

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[2] Collet, B.P. 4632 of 1877.

Preparation of Cyanotype Paper.—The following formula is suitable:

Solution A			
Gum arabic	6 ounces	170 grams	
Water	23 "	650 cc.	
Solution B			
Tartaric acid	617 grains	40 grams	
Water	5 ounces	135 minims	150 cc.
Ferric chloride solution Specific gravity 1.453	4 ounces	113 cc.	

This ferric chloride solution contains 47 per cent ferric chloride. Distilled water should be used in preparing these solutions, when mixing the stock solution the acid solution is added to the gum solution, and the ferric chloride added last. The mixture should be allowed to stand 24 hours and then diluted with water until it has its specific gravity of 1.0.

The paper is coated in the same manner as ordinary blueprint papers.

The Vandyke Process.—This process is used chiefly for making copies of tracing plans to be used subsequently as a negative for blueprinting. It produces white lines on a brownish-black background. The paper is coated with a light sensitive iron salt and silver nitrate in a solution of gelatin. Upon exposure to light, the ferric salt is reduced to the ferrous which in turn reduces the silver nitrate to metallic silver when the print is placed in water. Some of the silver nitrate is reduced to silver by the exposure but this is a secondary factor in the formation of the image.[3]

Papers of this type are obtainable commercially in various grades. Sensitized cloth is also available.

The paper is exposed to daylight, or a strong source of artificial light, in the same way as blueprint paper. The image appears as white lines on a light brown ground. After the exposure, the print is washed in running water one or two minutes and then placed in a 2 per cent solution of hypo. Fixing requires about five minutes, after which the print is washed for 10 to 15 minutes and dried.

The following is a suitable sensitizer for preparing paper of this type:

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[3] Arndt and Troost, D.R.P., 6,317 of 1894.

Solution A		
Ammonio citrate of iron, green	1344 grains	175 grams
Water	16 ounces	1 cc.
Solution B		
Gelatin	230 grains	30 grams
Water	8 ounces	500 cc.
Solution C		
Silver nitrate	385 grains	50 grams
Water	8 ounces	500 cc.

Soak the gelatin in water for fifteen minutes and then dissolve by heat at 45° C. (100° F.), filter and add *A*. Then add *B* but do not stir. Keep the solution warm while sensitizing the paper.

The sensitizer is applied in the same way as when sensitizing blue-print paper and it should be dried rapidly, although not at so high temperature as ferroprussiate or cyanotype paper.

Kallitype.—Unlike the processes described previously, the uses of which are restricted to the reproduction of plans and sketches, Kallitype is suitable for subjects of a pictorial nature.

There are two methods of working the process; in the first, the paper is coated with a ferric salt, usually the oxalate, and silver nitrate. Upon the exposure to light the ferric salt is reduced to the ferrous, and upon development in a solution containing borax and rochelle salt, the silver nitrate is reduced to metallic silver. The second method consists in the use of the iron salt alone as a sensitizer, followed by development in a solution of silver nitrate.

The formulas which follow are due to James Thomson.[4]

Citrate of iron and ammonia (brown)	32 grains	73.4 gm.
Ferric oxalate	16 "	36.6 gm.
Potassium oxalate	33 "	75.4 gm.
Copper chloride	4 "	9.15 gm.
Citric acid	4 "	9.15 gm.
Silver nitrate	10 "	22.9 gm.
Oxalic acid	10 "	22.9 g.m
Gum arabic	10 "	22.9 gm.
Distilled water to make	1 ounce	1000 ccs.
Potassium bichromate solution (20 grains to the ounce or 45.7 gm. to 1000 ccs.) as required.		

[4] *American Photography*, 17 (1923), 442.

Thomson—Possible Substitutes for the Platinum Print. Amer. Phot., 11 (1917), 642.
Thomson—Kallitype. Amer. Phot., 17 (1923), 422.
Valenta—Kallitype (an excellent summary of previously published papers on the subject). Bibliography. Das. Atelier, 27 (1920), 10.

From 5 to 10 drops of the latter to each ounce of the sensitizing solution is the normal quantity but where greater contrast is desired, the amount should be increased.

After making, the solution should be stored in a dark place for 24 hours. Before sensitizing, it should be filtered through cotton.

Any good linen paper will serve if given a preliminary sizing. Either arrowroot or gelatin may be used for this purpose. Gelatin is perhaps the simpler. The following formula is suitable:

Gelatin	50 grains
Powdered alum	30 grains
Water to make	10 ounces

First allow the gelatin to swell in cold water and then with constant stirring add it and the alum to the remainder of the water and bring to the boiling point. The sizing solution may be applied with a broad flat brush or with a cloth pad. After coating, the sheets are suspended from one corner in a warm room and allowed to dry normally.

The sensitizing solution is applied with a flat camel's hair, rubber-set brush, and the paper is dried as rapidly as possible, using a moderate amount of heat.

Either daylight or a strong source of artificial light may be used for printing. The image is faintly visible and of a tawny hue. Usually only the shadows and some of the half tones will be visible when the paper is properly exposed.

The developer is as follows:

Silver nitrate	40 grains	91.5 gm.
Citric acid	10 “	22.9 gm.
Oxalic acid	10 “	22.9 gm.
Distilled water	1 ounce	1000 ccs.
For blue-black tones add sodium phosphate	2 grains	4 gm.

For use, take one part of stock solution to seven parts of water. Greater contrast may be obtained by using a more concentrated developer.

Immerse the print face down and turn over immediately to break bubbles which if permitted to remain will result in white spots. Allow the print to remain in the developing solution for one minute, rinse well and fix for five to ten minutes in a plain solution of hypo as follows:

Hypo	15 grains	3.4 gm.
Water	10 ounces	1000 ccs.

Finally, wash for fifteen to twenty minutes in running water.

Palladiotype.—The substitution of palladium for platinum results in a paper similar to platinotype except in the color of the image which is a warm-black rather than a cold, neutral black.

Like Platinotype, the paper is sensitive to moisture, and must be kept dry. After removing it from the tins in which it is sent out, any paper not immediately used should be returned to the skin and a wide rubber band placed around the lid.

The paper gives a very visible printing image, and exposure should be carried to the point at which all detail is seen.

The prints should be immersed with a quick sliding motion in a developer prepared as follows:

Sodium citrate	1 oz.	100 gm.
Citric acid	43.7 gr.	9.8 gm.
Water to	10 ozs.	1000 ccs.

The temperature of the developer should be between 60° and 70° F. For greater contrast add from two to four drops of a 2 per cent solution of potassium bichromate.

After development, clear in three successive baths of the same composition but diluted with 7 parts of water.

Diazo Processes.—A large number of processes based upon the sensitiveness of diazo compounds have been patented, but only a few papers of this type have actually been placed upon the market. The papers available are designed for making copies of tracings and drawings and for this purpose are tending to supplant the blue-print processes.

The fundamental reaction in these processes is the formation of a colored azo compound from the reaction between a phenolic or amino compound and a diazo compound. This reaction, which is termed *coupling,* takes place most readily with phenolic compounds in the presence of an alkali and with amino compounds in a neutral or slightly acid state. Most diazo compounds are sensitive to light; once decomposed they are unable to couple with an azo dye component and cannot, therefore, be converted into a colored dyestuff.[5]

Four types of diazo papers are possible:[6]

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[5] Murray, *Phot. Jl.,* 63 (1933), 6 (Suppl.).

[6] Spencer, *Phot. Jl.,* 58 (1928), 490.

1. Diazo compound *A* decomposed by light to *B;* developed by the application of a coupler *C* in alkaline solution which reacts to give a colored product with *A* but not with *B*.[7]

2. Diazo compound *A* and coupler *C* coated together but prevented from reacting by the presence of an organic acid. Such papers are developed by bathing in a weak alkali; or, by exposing to ammonia vapor.[8]

3. Diazo compound *A* & *C* coated together but with the latter compound modified by the formation of additional compounds in such a manner that it will not couple in a neutral condition, development being effected by breaking up the addition compound by ammonia vapor, heat or the like.

4. Diazo compound *A* which is decomposed by light into compound D capable of coupling with unchanged *A* on standing, or on making the paper alkaline.[9]

In the Ozalid paper of Kalle & Co., which is based upon the patents of Koegel and Neuenhaus, the paper is coated with a diazo anhydride which does not couple directly with an azo component in a neutral condition but takes place readily in an alkaline condition.

The paper requires approximately the same exposure as blue print paper and is exposed in the same way. Exposure results in a faint yellow image, the unexposed portions retaining the color of the diazo compound with which the paper is coated.

Development is effected by exposing the paper to ammonia vapor for 5–10 minutes, producing a reddish-brown positive copy from a positive or a negative from a negative. No washing is required; hence distortion due to the wetting of the paper stock is avoided and measure-

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[7] Green, Cross and Bevan, G.P. 56,606 of 1890; *Brit. J. Phot.*, **37** (1890), 637.

[8] Koegel and Neuenhaus, G.P. 376,385; 386,433, B.P. 234,818 (1926), B.P. 210,862 (1924).

[9] Feer, G.P. 53,455 (1889); *Jahrbuch*, **5** (1891), 529.

Murray—Diazo Compounds in Photography. Phot. J., **73** (1933) (Suppl.), 6.

Sedlaczek—Diazotype. Phot. Ind., **33** (1935), 1062, 1064, 1082, 1084, 1108; S.&I.P. (II), **7** (1936), 40.

Seyewetz and Mounier—Action of Light on Diazonium Compounds and Azo Dyes. Bull. Soc. Chim. Fr., **43** (1928), 827–838; S.&I.P., **8** (1928), 231–232.

Spencer—Photographic Applications of Diazo Compounds. Phot. J., **68** (1928), 490–494.

ments and computations may be made from the print as from the original tracing.

Diazo-type papers which do not contain an azo compound in the sensitive layer but are developed by sponging the exposed paper in an alkaline solution of the azo component are available commercially in England.[10]

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[10] Murray, *Phot. Jl.*, **63** (1933), 6 (April Suppl.).

[11] Diazo processes for preparing prints in color. Murray, *Phot. Jl.*, **63** (1933), 12 (April Supplement).

CHAPTER XXVII

PRINCIPLES OF THREE-COLOR PHOTOGRAPHY

Trichromatic Theory—Additive and Subtractive Synthesis.—All methods of three-color photography are based upon the fact, stated first as a theory by Wünsch, elaborated by Young (1807) and established experimentally by Clerk-Maxwell (1860), that all colors distinguished by the human eye may be duplicated by mixing in various proportions light of three fundamental, or primary, colors. These are red, green and blue. These color sensations are not duplicated by the admixture of any others, but from them every color sensation can be produced and also white.

If, for example, beams of white light are thrown upon a screen through red, green and blue filters as shown in Fig. 211, the combination of red and green produces yellow; green and blue-violet produces blue-green; and all three together produce white. Various other colors may be produced by the combination of the primary colors in various proportions. Thus the addition of green to red will produce orange-red, orange or yellow, depending upon the relative intensity of the green to the red; in like manner, the combination of green and blue-violet produces various shades of bluish-green and a combination

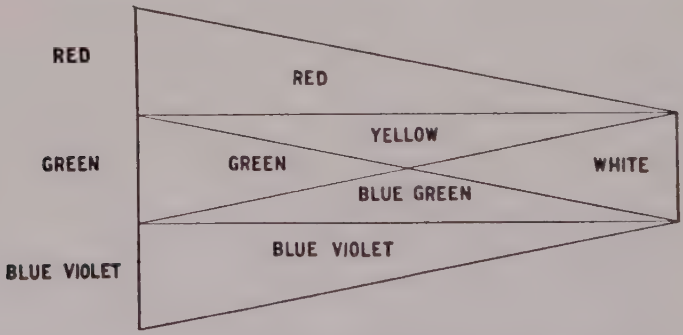

Fig. 211. Diagram of Additive Color Process Showing Mixture of Three Primary Colors Producing White Light

of red and blue produces all possible shades of violet from magenta through purple.

Using monochromatic light of these colors, the proportions in which each must be mixed in order to produce at any point in the spectrum, the same color sensation as is produced by the spectrum itself may be determined. In Fig. 212 are shown three color-sensation curves, one for each primary color. The heights of these curves at any particular wave length indicate the proportions in which the primary colors must be combined to produce the color sensation corresponding to that wave length of the spectrum.

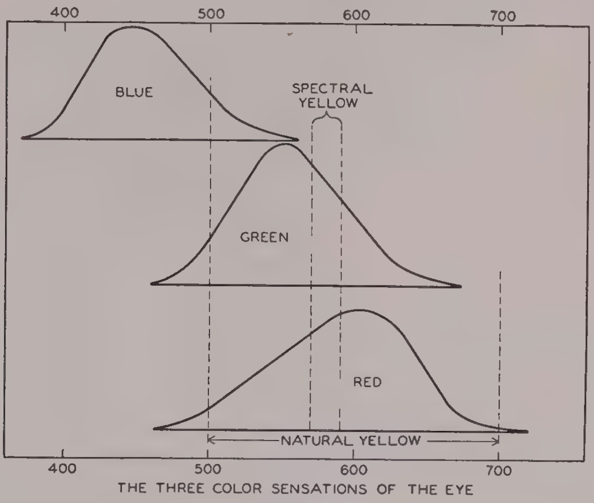

FIG. 212

Since in this case white light is produced by adding light of all three colors in the proper proportion, it is termed *additive synthesis.*

Color may also be produced by subtracting light of certain wave lengths from white light. Yellow transmits red and green and absorbs blue, yellow is in other words minus blue; that is to say, it contains all colors of the spectrum except blue-violet. If a yellow filter is placed on white paper and then over this a magenta filter which absorbs green light, as in Fig. 213, only red light will be transmitted. Similarly, a combination of a blue-green and yellow filters, produces green (Fig. 213) as the yellow absorbs the blue and the blue-green the red, leaving only the green, and a blue image may be obtained through a combination of magenta and blue-green filters.

Thus the three primaries, red, green and blue-violet may be produced by subtracting color from white light. This is known as *Subtractive Synthesis.*

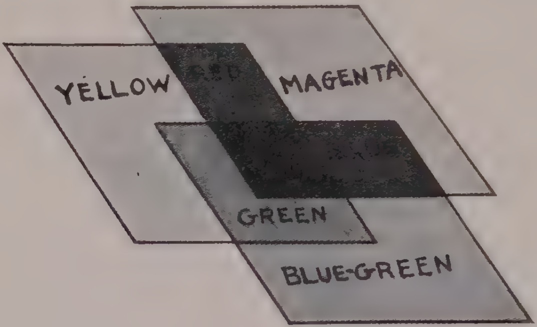

FIG. 213

Additive and Subtractive Processes of Color Photography.—Processes of three-color photography are conveniently divided into two classes: (1) *additive* and (2) *subtractive.* The first method, as its name indicates, depends upon the addition of colored light to colored light; in the second, or subtractive, method, color is produced by subtracting light of certain wave lengths from white light.

If a photograph is made using a red filter, the negative will record, in terms of density, the amount of red light reflected from the subject; in other words, the greater the amount of red reflected from any particular part of the subject, the greater the density of the corresponding parts of the negative. Areas which reflect no red light are completely clear while colors reflecting only a small amount of red are of low density.

A second negative made with a green filter will record the green and a third negative made with a blue filter, the blue reflected from the different parts of the subject. Colors formed of two or more of these colors will be recorded in two or more negatives in accordance with the amount of light of each primary color reflected. Thus the three negatives collectively will record in terms of density all the colors of the subject.

If positive transparencies are made from these negatives, color will be indicated by *lack of density.* In the positive from the red sensation negative, for example, the parts of the subject which are red will be almost clear, those containing some red by a low density and those containing no red by a comparatively high density.

This transparency when illuminated with red light will reproduce the red component of the various parts of the subject. In like manner, transparencies from the other negatives will reproduce the corresponding color components of the subject when illuminated by light of the same color as used in making the negatives.

It is now only necessary to superimpose the three colored images to produce a representation in full color of the subject photographed. This may be done in one of two ways: (1) the three positives may be placed in a specially designed triple lantern which is so arranged that the three images can be made to coincide upon the screen, or (2) the three positives may be placed beneath filters and the images superimposed with the aid of mirrors in an instrument known as a *photochromoscope* (Fig. 214).

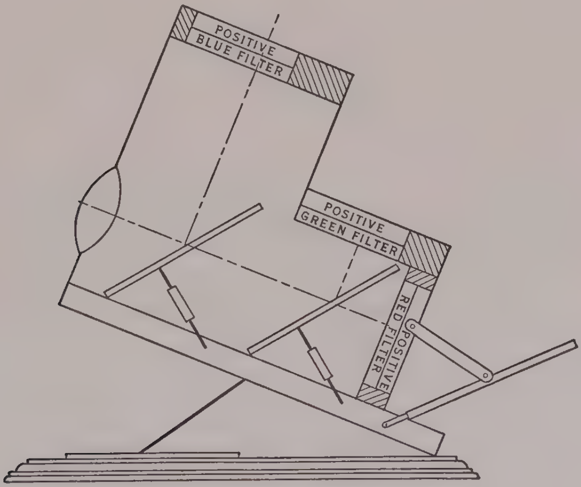

FIG. 214. Photochromoscope

Such methods of color photography have never been popular because of the expensive and inconvenient viewing or projecting devices required and are now only of historical interest. Screen plates, the historical development of which was traced in Chapter I, are now by far the most important of the additive processes of color photography.

Screen-Plates.—In just the same way that a painter may secure a certain color by the admixture of dabs of pigment of two or more colors which at a suitable viewing distance are no longer seen individually but combine to form a single color, so it is possible to secure all three color-sensation records on a single plate by exposing it behind, and in contact with, a screen composed of a large number of red, green and blue filters so small as to be indistinguishable to the unaided eye.

Screen plates may be divided into two types; in one the small filters are arranged in a regular pattern, in the other the differently colored filters are distributed at random throughout the screen. With screens of the first type, the screen may be on one plate, the photographic emulsion on another. The screen and the panchromatic plate are exposed in contact, the negative developed in the usual way and a positive transparency on glass made. This is then registered with a viewing screen, which has the same arrangement of the filters as the taking screen, and the two bound together. With screens of the second type in which the filters do not form any regular pattern, the emulsion must be coated over the screen. After exposure through the screen, the image is developed and then reversed to a positive.

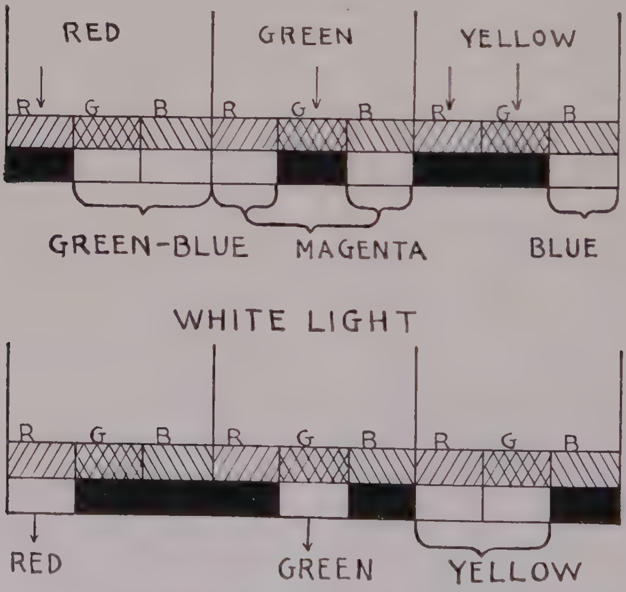

FIG. 215. Principle of Screen Plates

In Fig. 215, beams of red, green and yellow light are represented as falling on a screen composed of small filters designated *R* (red), *G* (green), and *B* (blue). Red light is transmitted by the red filter (*R*) and renders the emulsion beneath it developable. Green light is transmitted by the green filter and the emulsion beneath is rendered developable. Yellow light is transmitted by both the green and red filters, rendering the emulsion beneath both developable.

The deposits of silver produced upon development are shown by the darkened portions.

If the negative image is reversed to form a positive, or a positive is made from the negative and placed in register with the screen, red light is reproduced by the light transmitted by the red filters, since the green and blue filter elements are covered with the silver of the positive image. In the same way, green is reproduced by the light transmitted by the green filters, because the red and blue filter elements are obstructed by the silver deposit and yellow is reproduced by the light transmitted by the green and red filter elements, the blue only being obstructed by the positive image.

With a negative image, complementary colors are produced, the red being represented by a mixture of green and blue, the green by a mixture of red and blue known as magenta and the yellow by blue.

Subtractive Processes of Color Photography.—Three-color negatives may be made (1) by making three separate exposures with an ordinary camera changing the filters and the film, or plates, between each exposure, (2) by means of a repeating back which enables these changes to be made in a much shorter period of time, (3) a tripack in which three emulsions each recording one of the primary color-sensations only are placed in contact with each other and exposed and (4) a tricolor camera in which all three negatives are exposed at the same time and through the same lens. All of these methods will be described at greater length in the following chapter.

To obtain a print in colors from negatives produced by any of the above methods, it is necessary to superimpose on the paper three images of the proper colors. Since each of the three negatives constitutes a record in terms of density of the distribution of that particular color in the subject, it is obvious that the densities of the positive will indicate not the presence of that particular color sensation but its absence. In other words, the densities of the print from the red filter negative will indicate not the amount of red reflected by the corresponding portions of the subject, but the absence of red, that is the light of other colors. Hence, the color of the positive image will not be that of the filter used in making the negative, but complementary to it. In other words, the red filter negative will be printed in *minus* red or *blue-green;* the green filter negative in minus green, i.e., blue-red, which is termed *magenta;* and the blue filter negative in minus blue, i.e. green-red or *yellow.*

Subtractive Printing Processes.—The methods employed in making the color images for subtractive printing processes may be divided into seven classes:

1. *Pigment transfer.*
    - (*a*) Prints are made from the three negatives on trichrome carbon tissues, containing pigments the colors of which are complementary to those of the taking filters. These images in color are then superimposed to produce the completed print.
    - (*b*) Prints on developing paper are made from the three negatives and from these carbon prints are made by the carbro process. These prints are then superimposed to produce the color print. This method has the advantage over the pigment transfer method in that enlarged color prints can be made.
    - (*c*) Prints are made from the three negatives through the back of film coated with a light-sensitive silver halide emulsion and a pigment of suitable color. After exposure, the prints are developed in a developer having a tanning action, or are first developed and then treated in a solution which renders the gelatin in contact with the silver image insoluble. Washing in hot water dissolves the soluble gelatin and the silver image is removed by bleaching and fixing. The colored images produced in this manner are then stripped from their support and superimposed to form the color print.
2. *Toning and Dye Mordanting Processes.*
    - (*a*) Prints are made from the three negatives on a special stripping paper. These prints are then toned chemically to produce images of the required colors. The color images are then stripped from the paper and superimposed to form the final print.
    - (*b*) Prints are made from the three negatives and the developed silver image is changed to a compound which will absorb, or *mordant,* basic dyes. After dyeing with appropriate

dyes, the three images are superimposed one on the other. The dye is distributed throughout the gelatin film so that the entire film must be transferred to the final support.

3. *Relief Processes.*

(*a*) Prints are made from the three negatives and an image of tanned gelatin produced (1) by developing in a developer which differentially hardens the gelatin according to the density of the developed silver image or (2) by developing in an ordinary developer followed by treatment with a bleaching solution which produces the same result. The fixed-out images are then washed in hot water to remove the soluble gelatin, stained in appropriate dyes and superimposed to form a transparency in colors.

(*b*) The original negatives, or duplicate negatives are placed in a solution of an oxidizing agent, such as hydrogen peroxide, which dissolves the image and attacks the gelatin surrounding the silver grains. The gelatin film is then washed, fixed and stained with suitable dyes. The three dye images are then superimposed to form a color transparency.

4. *Imbibition Processes.*

Paper prints may be prepared by staining up relief images produced by any one of the processes described under (3) with dyes which will transfer to paper coated with soft gelatin. Each of the three stained gelatin reliefs, or " print plates " is placed successively in contact with the gelatin coated paper. The dyes in the print plates are absorbed, or " imbibed "—hence, the term imbibition—by the gelatin and in this way three dye images are superimposed on the gelatin coated paper to form a color print.

5. *Developed Color Images.*

The oxidation products of certain developers, notably indoxyl and thioindoxyl, form brightly colored images. Attempts have been made to employ such processes to the making of prints in color but without much success.[1]

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[1] Homolka, *Brit. J. Phot.*, **54** (1927), 136, 196, 216. *Photo. Korr.*, 1914, **51**, 256, 471. *Jahrbuch*, 1914, **28**, 22. Fischer, *Brit. J. Phot.*, 1913, **60**, 595, 712, and 1914, **61**, 329. Ermen, *Brit. J. Phot.*, 1923, **70**, 47. Capstaff, *Brit. J. Phot.*, 1915 (62). (Col. Suppl. **9**, 17); B.P. 13,429 of 1915; U.S.P. 1,196,808 and 1,315,464.

6. *Selectively Hardened Gelatin Processes.*

These processes are based upon the difference in the dye absorbing properties of hardened and unhardened gelatin. They differ from the processes discussed under (3) in that the whole of the gelatin remains, while in the processes discussed under that heading a gelatin relief is formed through the removal of a part of the original gelatin layer.

The negatives, or duplicate negatives, are placed in a tanning bleacher which removes the silver image and hardens the gelatin in proportion to the density of the original silver image. This results in colorless negative images of differentially hardened gelatin which are then stained to produce positive dye images using dyes which are absorbed only by soft gelatin. The dye images are superimposed to form color transparencies or color prints on paper made by imbibition.

7. *Processes Based Upon the Bleaching of Dyes.*

Positive transparencies are made from the three color-sensation negatives and prints from these on paper sensitized with a diazo compound. The dye is bleached in the parts exposed to light, producing a positive image which is developed by the application of a developer which converts the diazo compound into a stable dye image. Since it is the unexposed diazo compound which is used in the formation of the image, it is evident that a positive is obtained from a positive, thus it is necessary to print from positives rather than the original negatives.

A number of processes of this type have been patented in recent years but none has reached the commercial stage. There is no difficulty in finding a suitable red; but suitable blues and yellows are rare.[2]

Subtractive Processes Based Upon an Integral Tripack.—Ducos du Hauron, who seems to have anticipated almost every possible process of color photography, suggested the use of three emulsions each separately sensitized to one of the three primary color sensations superimposed as a means of making three color negatives. The simplest method of making such a tripack is by superimposing suitable emulsions coated on three separate films.

[2] Spencer, *Brit. J. Phot.*, 1928, Col. Suppl. **22**, 30.

Tripacks in which the three emulsions are coated over one another on the same film are termed *integral* tripacks. The first tripack of this type to be introduced commercially for camera use was developed in the Research Laboratories of the Eastman Kodak Company and introduced as *Kodachrome,* first for amateur cinematography and then as roll film and cut film for still cameras. Other integral tripacks in commercial use are *Agfacolor* and *Gasparcolor.*

Kodachrome.—A cross section of developed Kodachrome film is shown in Fig. 216. The surface emulsion is sensitive to blue and violet only, the second emulsion is of the orthochromatic type sensitive to violet, blue and green. A yellow filter dye incorporated in the gelatin layer between the two emulsions absorbs the violet and blue so that the second emulsion responds only to green. The third emulsion is sensitive to red but not to green. Thus, the three separate color sensation records are secured on the one film.

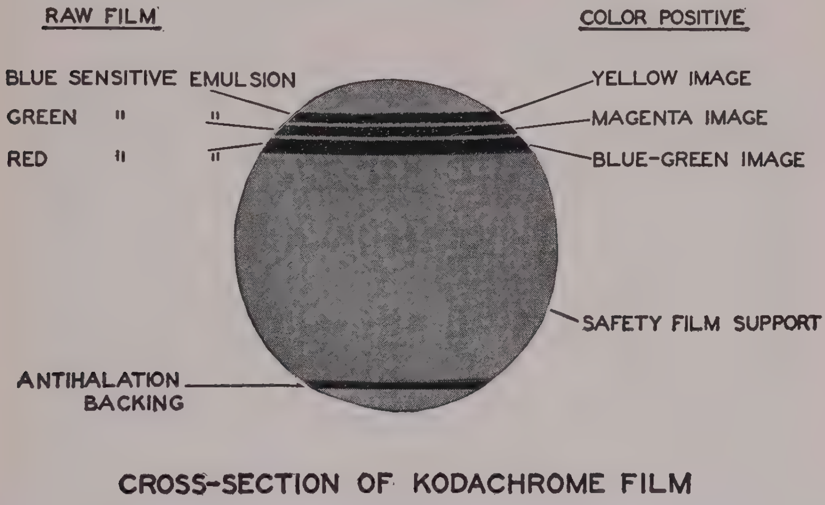

FIG. 216. Cross-Section of Kodachrome Film. (Eastman Kodak Co.)

The 16 and 35 mm. film is supplied in two types, *Regular* designed for use without filters by daylight and *Type A* designed for use with Photoflood lamps and requiring filters for use in daylight. Kodachrome professional film (in cut sheets) is also supplied in two types; Daylight, and Type B, for incandescent tungsten light (3200° K).

In processing, the latent images in the three layers are developed in the normal way after which the metallic silver of the image is removed leaving the unexposed silver halide. The film is then exposed and the silver halide developed in a special color developer which results in an image consisting partly of silver and partly of a blue-green dye. The film is then bleached a second time, the operation being so controlled that only the first two emulsion layers are affected. This operation converts the two upper images to silver halide again, leaving the bottom image unaffected (i.e., blue-green). The film is again exposed and developed in a second developer which produces an image consisting of silver and a magenta dye. The upper layer is then bleached and redeveloped, this time with a developer producing an image consisting of silver and a yellow dye.

At this stage, the film contains developed silver in all three layers, with a yellow dye in the upper, a magenta dye in the middle and a blue-green dye in the lowest layer. In the final operation, the silver images are bleached and removed leaving the three dye images. Since these are complimentary to the color sensations recorded by the three negative images, it is obvious that the result is a positive image of the subject in natural color.

Owing to the complicated processing technique necessary and the high degree of precision with which the various operations must be controlled, the film cannot, in its present state, be processed by the user but must be sent to the Eastman Kodak Company for processing.

Agfacolor.—The Agfa process utilizes an integral tripack and has been designed primarily for motion picture purposes. It differs from Kodachrome in that the dye-forming constituents necessary for the production of the three color-images are incorporated in the different emulsions during manufacture. The film is first developed to a negative in an ordinary developer, then exposed to light and developed in a special dye-coupling developer whereupon the colored dye images are built up in each layer. The black metallic silver is then dissolved, leaving a three-color subtractive print of the subject photographed.

Gasparcolor.—Garsparcolor is an integral tripack process, the colors being incorporated in the emulsion. The blue-green colored emulsion, which is sensitive only to blue light, is coated on one side of the film and the yellow colored emulsion, sensitive to red light, on the

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Forrest and Wing—The New Agfacolor Process. J. Soc. Mot. Pict. Eng., **29** (1937), 248.

other. A magenta colored emulsion, sensitive only to blue light, is coated over the yellow layer.

At the present time, the film is used only for printing from three-color motion picture negatives obtained in specially designed cameras.

"Printing takes place from three separation positive films by means of appropriately coloured lights. Thus, when the yellow printing separation positive is printed on to the film by means of red light, this light does not affect the top magenta, blue sensitive layer, and the image is, therefore, only recorded in the middle yellow-coloured layer.

"The magenta and blue-green printing positives are then printed by blue light on to the outer magenta and blue-green coloured emulsions. The exposed film is developed and then treated with a reagent, which converts the silver image into silver bromide—an operation which causes the dyestuff in the immediate neighborhood of the silver image to bleach. The silver halide is then fixed out, leaving a subtractive three-color positive image."[3]

Additive and Subtractive Processes Compared.—The principal disadvantage of the additive processes is that they are not suitable for prints on paper. For other purposes, such as motion pictures or lantern slides, additive processes are not as satisfactory as subtractive processes (1) because of the amount of light absorbed by the filters, which renders the images dark and somewhat dull unless a powerful light is used, and (2) because the only practical additive processes necessitate a multi-color screen, which produces either a granular appearance or a pattern, depending upon the type of screen, upon projection. The possibility of making prints on paper for viewing by reflected light makes subtractive processes by far the more important commercially.

Two Color Processes.—Pleasing, although obviously incomplete, pictures in color may be obtained of certain subjects using only two of the three primary colors. Two color negatives can be made with one exposure, in an ordinary camera by using a bipack (see p. 537) and printing processes employing two images are naturally simpler than those employing three colors. The complications of the three-color processes have led numerous investigators to attempt to perfect two color processes particularly for making motion pictures in

[3] Spencer, *Phot. Jl.*, 77 (1937), 84.

Jacobsohn—The Gaspar Process of Colour Photography. Brit. J. Phot. (Colour Suppl.), 27 (1933), 29.

color. There is at present little interest in two color processes and it is probably safe to say that such processes are now of historical interest only.

In two color processes, the spectrum is either divided into approximately equal parts by the taking filters, the orange and red being recorded on one negative, and the green and blue on the other, or one of the primaries is ignored altogether, the two selected depending upon the type of subject for which the process is designed.

When the spectrum is divided into two approximately equal parts and the prints are made in colors complementary to those of the taking filters, flesh values are reproduced quite well.

Yellow and purplish-blue are not included, nor white, although as DuHauron pointed out, the yellow sensation is produced if the results are viewed in a yellowish light and the degraded whites produced by two-color processes frequently appear practically white due to the contrast of the other colors. Suggestions have been made that the usual three-color prints be made, the yellow image being exposed partly from the blue-green and partly from the red negative; while such methods, under certain circumstances, produce pleasing results, it is obviously impossible to reproduce natural colors in this manner.

CHAPTER XXVIII

THREE-COLOR NEGATIVE MAKING AND SUBTRACTIVE PRINTING PROCESSES

Requirements of Three-Color Negatives.—Since all three negatives must be superimposed in the final print:

1. The three images must be the same size in every detail.
2. The three images must be made from the same position.
3. The three images must be equally sharp in all portions.

Since each negative must represent in terms of density, the amount of light of its particular primary reflected from the different parts of the subject:

1. The filters must divide the spectrum into three approximately equal parts with some overlapping to ensure complete coverage. (See following pages.)

2. The rendering of a scale of greys must be the same in all three negatives. This is necessary (1) to obtain color-free rendering of white and greys, (2) to ensure the proper balancing of the colors records when making the print.

Filters for Three-Color Photography.—While it might appear that the transmission of the three filters should correspond with those representing visual color sensation (p. 517), this is not the case, for such filters, due to their excessive overlap, result in degraded colors. For example, a red in the region of 610 is produced by the admixture of red and green light, producing the sensation of orange. If the intensity is low, as in the case of a deep orange-colored shadow, only the light transmitted by the red filter will be recorded, so that the color will be reproduced as a dark red. On the other hand, if the intensity is high, as a bright orange highlight, the color will be recorded in both the green and red negatives and thus will be recorded as a yellow since red and green together produce yellow. Similar conditions apply in nearly all parts of the spectrum, except in the extreme red and violet, owing to the overlapping of the transmission curves of the different filters. It is evident, therefore, that with such filters the reproduction of color varies with the exposure. Color photography, however, must record differences in brightness as well as in hue and it is necessary that regardless of the variation in brightness, the correct hue be reproduced.

From this it is evident that the transmission curves of the three filters should be as abrupt as possible and overlap only slightly. The ideal filters would have curves as shown in Fig. 217. Three such filters divide the spectrum into five regions each of a practically uniform hue. From 600 mμ to 700 mμ is recorded in the red filter negative only, the region between 580 mμ and 600 mμ is recorded through both the green and red filters and is reproduced as yellow, since yellow results from the admixture of red and green light. The region between 500 mμ and 580 mμ is recorded only in the negative made through the green filter, while the region between 480 mμ and 500 mμ is recorded in both the green and blue filter negatives and, therefore, is reproduced as blue-green. The region between 400 mμ and 480 mμ is recorded only on the blue filter negative and is reproduced as blue. While these filters are unable to distinguish between hues which lie totally within any of these spectral regions, in practice this is not serious, since no naturally occurring colors are pure, but all reflect some white in addition to light of colors other than that of its dominant hue.

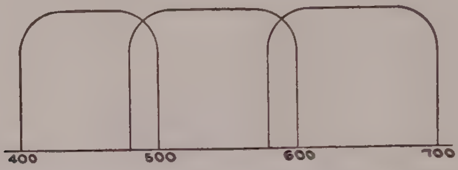

Fig. 217. Curves of the Ideal Three Color Filters (Photography of Colored Objects)

While the dyes available do not permit of exact duplication of the ideal filters, a sufficiently close approximation is possible. Spectrophometric curves showing the transmission of a well-known set of three color filters (Wratten, No. 25 (red), No. 58 (green) and No. 47 (blue-violet) are shown in Fig. 218. The transmission curves of the red and the blue filter approximate the ideal very closely; the transmission of the green filter ends less abruptly at the long wave region than that of the ideal. While this can be overcome by increasing the red absorbing component of the green filter, this is not practical because of the increase in the filter factor, necessitating greatly increased exposure.

Sets of filters for three-color photography are supplied by the leading manufacturers. The Wratten Tri-color Filters, the Agfa Three-color filters No. 40 (blue), No. 41 (green) and No. 42 (red), and the Ilford Tri-color red, green and blue are among the best known in this country. While the filters are similar, it is advisable to use the set advised by the manufacturer of the sensitive materials employed.

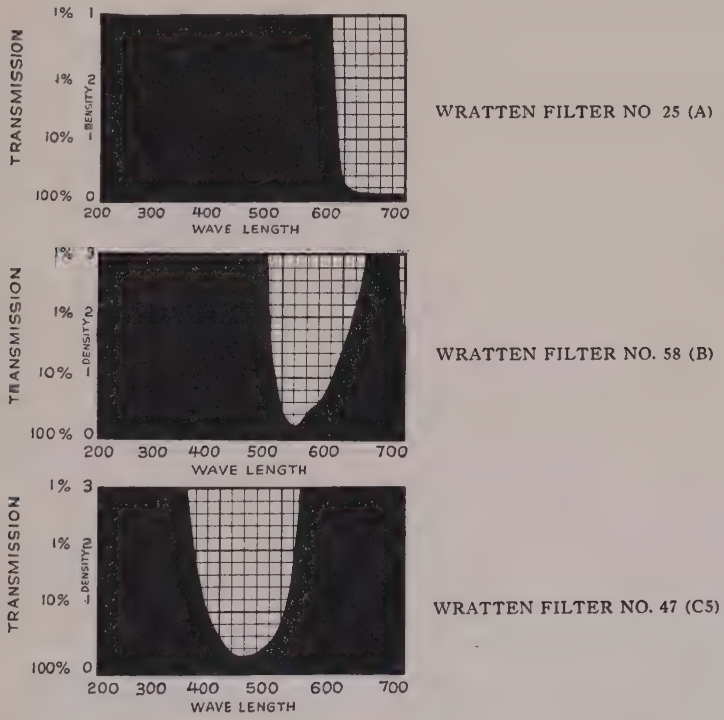

FIG. 218. Spectrophotometric Curves of the Wratten Tricolor Filters. (Wratten Filters)

If filters cemented in glass are used in front of the lens, it is imperative that these be of the best quality. For critical work, either gelatin filters, or matched sets of filters in optical flats, should be used to prevent differences in the size of the three images.

Methods of Exposing Three-Color Negatives.—Three-color separation negatives may be made in any one of four different ways:

1. With an ordinary camera, the plate and filter being changed between each exposure.

2. With a camera having a repeating back in which the plate and filters are changed automatically.
3. With a tripack.
4. With a one exposure three-color camera.

With an Ordinary Camera.—For still objects an ordinary camera may be used, the three negatives being made by successive exposures, the filters and the plates or films being changed between each exposure. The exposure must be adjusted, of course, in accordance with the multiplying factors of the filters. Care must be taken that the lighting does not change during the time the three exposures are being made and a rigid camera and tripod used to prevent any danger of shifting when changing plates and filters. Neither portraits nor landscapes in which movement is likely can be photographed in this way.

Repeating Backs.—An improvement over the ordinary camera with separate plates or film holders is provided in a repeating back. The holder of the repeating back takes a plate long enough for the three exposures to be made on the one plate and the filters are placed in front of the plate so that they are changed automatically as the plate is shifted for the different exposures. In some cases, the repeating back is shifted from one exposure to the next by hand and in other cases the holder automatically drops into position for the next exposure when the shutter closes. With repeating backs of this type all three exposures may be made in the space of three or four seconds.

Tripacks.—The three-color sensation negatives may be made with a single exposure in an ordinary camera by using a *tripack*. A typical tripack consists of three separate films. The film in front is coated first with an ordinary (blue-sensitive) emulsion and then with a layer of gelatin containing a yellow filter dye. The second film is coated on the front side with an orthochromatic emulsion sensitive to green but not to red and on the back with a gelatin layer containing a red filter dye. The rear film (third) is coated with a panchromatic emulsion. Thus upon exposure in the camera, a blue-violet sensation negative is obtained from the front film, a green sensation negative from second and a red sensation negative from the third.[1]

There are four drawbacks to the widespread use of the tripack as a means of making three color negatives:

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[1] Patents on tripacks: Klein and Color Snapshots Ltd., B.P. 326,559. T. Thorne-Baker, B.P. 321,998. See also Wall, History of Color Photography.

1. *Unsharpness of the second and particularly the third images.* The scatter of light in the first emulsion necessarily results in a loss in definition in the second image and since such effects are cumulative, the loss in definition is even more marked in the third image. This limits the tripack to work in which a critical sharpness is not required.

2. *The latitude in exposure is small.* This is due to the fact that the first and second emulsions must be as thin as possible in order that the maximum amount of light may reach the rear film and thin emulsion layers have little latitude because any increase in exposure leads to the maximum density which the film will produce.

3. *Securing balanced exposures.* This is due to the difficulty in adjusting the relative speeds of the three emulsions so as to obtain equal densities on all three negatives with the same exposure. This is a difficult manufacturing problem.

4. *The time of exposure is comparatively long.* Owing to the absorption of light in the first two films, a comparatively long exposure is required for the rear negative despite the fact that a highly red sensitive panchromatic material is employed.

Tricolor Cameras.—Tricolor cameras are designed to optically divide the light transmitted by the lens in such a way as to produce two or three separate images in different planes. These images, individually filtered, enable the three-color separation negatives to be made with a single exposure. Many different types of tricolor cameras have been developed through the years[2] but only those in which the light transmitted by the lens is divided by partially reflecting mirrors are of importance today. These may be divided into two classes: (1) cameras employing two reflectors to produce two reflected and one direct image, and (2) cameras employing one reflector to produce one reflected and one direct image, two of the color-sensation negatives being obtained by means of a bipack (p. 537) and the third on a separate film.

Two representative optical systems used in double mirror tricolor cameras are shown in Fig. 219. In (1), the two mirrors are at right angles to each other so that one reflected image is either above or to the left of the direct image, the other below or to the right. The advantage of this arrangement over some others is that the tendency

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[2] Details of cameras described or patented before 1925 may be found in *The History of Three-Color Photography* by E. J. Wall, American Photographic Publishing Company, Boston, 1925.

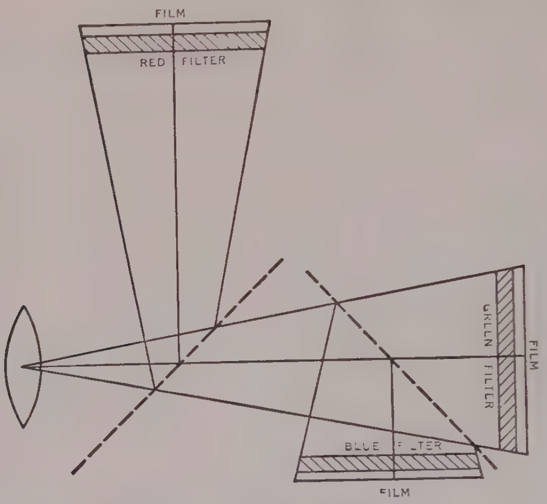

FIG. 219. Tricolor Camera (1)

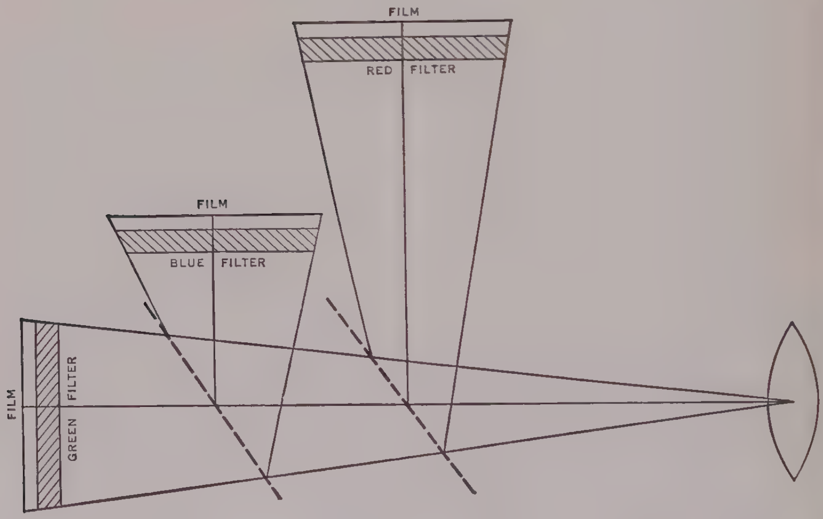

FIG. 219. (2)

towards uneven illumination of the direct and second reflected image is exactly corrected by having the mirrors at right angles.[3]

In (2) the two mirrors are parallel. The disadvantage of this arrangement is that the direct and the second reflected images are graded in intensity from top to bottom unless the mirrors are slightly deformed, which adds to the expense of construction and the difficulty of adjusting the camera.[4]

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[3] This construction was patented by White, B.P. 8,663 of 1896.

A third arrangement places the first reflected image above and the second to the right of the direct image. In this construction, the foreshortening produced by the first mirror is corrected so far as the direct image is concerned by the second mirror; a compensating plate is necessary, however, to correct the second reflected image.

The optical construction of the single mirror camera is shown in Fig. 220; the direct image is formed on a bipack, the reflected image on a single film. In one arrangement, a yellow filter is placed in front of the bipack and the green filter negative is obtained on the front member; the red filter negative on the rear member and the blue filter negative from the reflected image. Since the direct image, which is much brighter than the reflected, is used for the bipack where filters are necessary and the reflected image for the blue sensitive emulsion which is used without a filter, comparatively short exposures are possible. In fact, this construction probably permits of shorter exposures than any other type of tricolor camera. A second arrangement places a magenta (red and blue transmitting) filter in front of the bipack so that the blue filter negative is obtained on the front member and the red filter negative on the rear member of the bipack, the reflected image being used for the green filter negative.

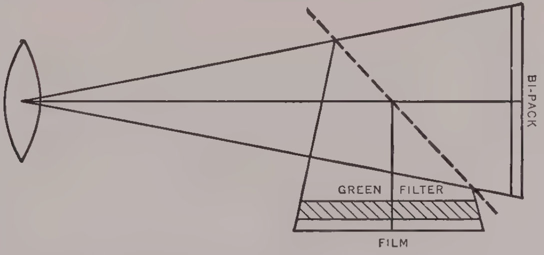

FIG. 220. Single Mirror Tricolor Camera Using Bipack

The performance of the single reflector camera depends upon the quality of the negatives produced by the bipack, i.e. on (1) the color separation obtained, and (2) the sharpness of the image obtained on the rear negative of the bipack. On the other hand, the single reflector camera, being much simpler than the double reflector camera, is less expensive and permits shorter exposures.

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[4] Butler, B.P. 29,353 of 1897.

The partially reflecting mirrors used in tricolor cameras are made (1) of glass, either plain or coated with a semi-transparent metallic reflecting surface of electrolytically deposited silver or platinum, or (2) of thin membranes of collodion stretched over an optically flat frame. These last are termed *pellicule mirrors.*[5]

Glass mirrors have a number of disadvantages. Mirrors of plain glass reflect very little light so that the direct image is always much brighter than the reflected image. This disadvantage is overcome if the surface of the glass is coated with a semi-transparent reflecting layer of metallic silver or platinum, but such surfaces are difficult to prepare and are expensive. In addition, the surface tarnishes in time and must be refinished.

A second disadvantage of glass mirrors arises from the distortion of the direct image by the mirror. This distortion causes one half of the image to be expanded, the other half contracted, making accurate registration of the three images difficult.

A third source of difficulty arises from reflection from both sides of the glass producing double images. This difficulty may be overcome by making the reflector serve as a filter so that the light which would be reflected from the underside of the glass is absorbed. The color of the filter is made complementary to that of the taking filter so that only the light reflected from the front surface is utilized in the reflected image.

Most of these difficulties are overcome by using pellucle mirrors as these are so thin that there is no appreciable distortion of the direct image nor is it necessary to color the back of the mirror to prevent double reflections. They are, however, more easily damaged and unless carefully mounted, are affected by changing climatic conditions.

Sensitive Materials for Three-Color Photography.—Three separate combinations of negative materials are possible:

1. *A panchromatic material is used with suitable filters for all three negatives.* This is perhaps the best method when the negatives are exposed separately in an ordinary camera or with a repeating back. Since the same film or plate is used for all three negatives, differences in emulsion characteristics are avoided.

2. *An ordinary (blue-sensitive) film or plate is used for the blue-*

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[5] Reckmeier, B.P. 357,372 of 1929. Klein, B.P. 380,928 of 1931. *Bull. Soc. franc. Phot.,* 1933, 24. Spencer, *Phot. Jl.,* **74** (1934), 103.

sensation negative, an orthochromatic material with a yellow filter for the green-sensation negative and a panchromatic material with the usual tricolor red filter for the red sensation negative. This combination results in a higher speed since the dense blue tricolor filter is avoided and only a yellow filter with a low filter factor is required in place of the tricolor green filter. This combination is frequently used in double reflector tricolor cameras because of its higher speed. The three emulsions, however, should be of the same general character, except for the difference in sensitizing. It is important with such a combination to avoid overexposure of the blue-sensation negative or good color separation will not be obtained.

3. *An ordinary (blue-sensitive) plate or film is used without a filter for the blue-sensation negative, and the same panchromatic material with suitable filters for the green and red sensation negatives.* This combination is faster than (1) and has the advantages over (2) that the two most important color records, the green and the red are made on the same emulsion.

For three-color photography, glass plates have the advantage of being free from unequal expansion or contraction in processing which would disturb the registration of the three-color images. Experience has shown, however, that films may be used if all three are on the same type of base, receive the same treatment in processing and are dried slowly and uniformly in the same direction.

Double reflector cameras are ordinarily adjusted to produce balanced exposures on some particular combination of films or plates and the choice of sensitive materials is limited by the requirements of the camera.

When a tricolor camera is used, the choice of sensitive materials is limited by the requirements of the camera. Single reflector cameras necessitate a bipack and a separate film or plate for either the blue or green-sensation negative. The bipack consists of two separate films which are exposed together, the front film being placed with its back to the lens so that the emulsions of the two films are in contact. The front member of the bipack may be either an ordinary (blue-sensitive) or an orthochromatic emulsion. Coated over it is a layer of gelatin containing a red filter dye which serves as a filter for the panchromatic emulsion in the rear. When the front film is orthochromatic, it is ordinarily used in conjunction with a yellow filter for the green-sensation negative, the reflected image being used for the blue-sensation negative. When the front film is an ordinary emulsion, it is used for the blue-sensation negative and the reflected image for the green sensation negative. In both cases, the rear member of the bipack is used for the red-sensation negative.[6]

One drawback to the bipack is the poor definition of the rear, or red sensation, negative. This is due in part to the separation of the two emulsions, but to a greater degree to the irradiation in the front film and can be reduced by making the emulsion more transparent, but as the emulsion becomes more transparent, its latitude and contrast become less, so that the improvement possible in this direction appears limited. Considerable progress has been made, however, during the past year and bipacks recently introduced represent an advance in this respect over those of a few years ago.

Lighting in Color Photography.—Daylight is perhaps the most suitable form of illumination although either the plain arc or incandescent electric lights may be used. In the latter case, however, the clear glass and not the blue glass bulb should be employed. A softer lighting than would be desirable in black and white work is usually required. Hard direct lighting tends to reproduce pale tints, particularly if yellow, as white. It should be remembered that since the colors will contribute towards the modeling of the subject, the necessity for creating form by shadows, as in black and white work, is not so vital. It is best to use a comparatively large amount of reflected light for the main source supplemented with one or two diffused floodlights.

It is vitally important in the case of artificial light that all of the lamps used be of the same type, as the color of the light will naturally effect the colors of the subject. For example, if an object is illuminated on one side by incandescent lamps and on the other side by daylight, or by a white flame arc, the eye will see one side as a yellowish white and the other as a bluish white, and no amount of manipulation will alter it.

Lens.—A good anastigmat should be used for making three-color negatives; other lenses (excepting process lenses) may not produce images of the same size or sharpness on all three negatives.

It is advisable to use a lens hood to minimize the effects of scattered light and flare.

Reference Object.—Since it is necessary that the three negatives balance as regards density and contrast, it is advisable to include in the picture a reference object consisting of a scale of gray tones. The reference object should be placed to one side where it will receive approximately the same light as the subject but may be removed from the finished picture by trimming. If the reference object is placed so that it is along one margin of the negative, comparison of the densities on the different negatives is simplified. The reference object should be large enough to form steps about 3/16 inch square on the negatives to permit of measurement in a densitometer. For small objects, the Wratten copyboard chart (Fig. 221) forms a convenient reference object; in addition to a scale of greys it contains registration lines and colored areas for identifying the three negatives. A suitable scale of greys may be made by exposing of a sheet of developing-out paper in steps and developing so as to obtain a neutral black deposit.

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[6] Patents on Bipacks: Dupont Film Mfg. Co., B.P. 369,799 and 388,774. T. Thorne-Baker, B.P. 328,336. See Wall, History of Three Color Photography.

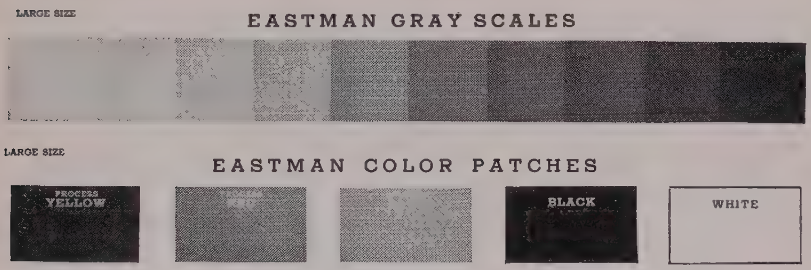

FIG. 221.

Filter Factors and Exposure.—With a panchromatic material, the filter factors for the set of three-color filters approved by the manufacturer are determined by test for each emulsion number and printed on a card which is packed with the films or plates. While these values are accurately determined, they should not be accepted as final, since the factor of a filter depends upon a number of considerations (see p. 231) for which it is difficult to make allowance. When photographing inanimate objects, with an ordinary camera or a camera fitted with a repeating back, it is sufficient to expose the three negatives as indicated by the published factors and then after developing compare the reference object in the three negatives and determine the alterations in exposure necessary for equal densities on the scale of greys. In the case of outdoor subjects, portraiture and subjects with which such a plan is impractical, the exposure ratios may be determined by photographing a neutral black and white image with each of the three filters, employing the same lighting conditions and negative material, and determining the exposure necessary in each case to produce equal highlight densities.[7]

In a tricolor camera, all three negatives of a black and white print should match. Since in cameras of this type, the *time* of exposure is usually the same for all three negatives, variation in the filter factors must be compensated for either by using a suitable filter of the orthochromatic type or through neutral density filters.

There is much less latitude in exposure in three-color work than in black and white and correct exposure is absolutely necessary if the best reproduction of color is to be obtained. Overexposure tends to dilute the colors with white, underexposure dilutes the colors with black. The exposure should be adjusted to utilize, as far as possible, the straight line portion of the characteristic curve of the negative materials, when all three negatives are developed to the same gamma.

Development.—It is essential that each of the color separation negatives be developed to approximately the same gamma. When all three negatives are developed together for the same time, the blue filter negative usually has less contrast, or a lower gamma, than the other two.[8] For this reason, it is frequently advised that the blue filter negative be developed from 25 to 100 per cent longer than the other two in order that the contrast of all three will be identical. The increased time of development necessary under given conditions can be determined either by sensitometric methods, or by trial and error, using the grey scale as a guide.

The contrast (or gamma) to which the negative should be developed depends upon the method used in making the three-color print. If the printing process increases contrast, the contrast of the negative must be correspondingly lower than that of the subject, while if the contrasts of the positive are lower than those of the negative, the negative must be developed to a higher degree of contrast. In general, soft, well graded negatives with rather less contrast than would be desired in black and white work are desirable.

A successful set of negatives depends to a large extent on the care taken in developing. Uneven development will result in color patches when the negatives are printed and no amount of retouching or faking will make this right. The eye is much more sensitive to changes in color balance than it is to changes in tone, which necessitates special care in development to avoid any unevenness.

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[7] For other methods of determining filter factors, see p. 232.

[8] The difference is less marked with some of the newer panchromatic materials than with the old.

When developing in a tray, a fairly large volume of developing solution should be used and the time of development should be at least five minutes to reduce the danger of non-uniform development.

With tank development, particular attention must be given to the manner in which the negatives are agitated, as too rapid agitation results in edge markings, while lack of agitation produces flow marks caused by the by-products of development liberated from the dense portions of the negative spreading to adjoining areas and restraining development. Where possible, it seems best to pour off and replace the developer at fairly frequent intervals during development.

The negatives should be marked before development with filter used in order to facilitate identification.

The Chromatone Process.—This process is based upon a stripping paper developed by the Defender Photo Supply Company of Rochester, New York, and methods of metallic toning perfected by F. H. Snyder and Company of New York City. Materials for the process are a product of the first-mentioned firm.

The stripping paper consists of a chloro-bromide emulsion coated on a thin layer of collodion which is separated from the paper base by a water-soluble layer. Prints are made from the three negatives as on any developing power. The images are then stripped from the paper base, toned, and superimposed on a sheet of gelatin coated paper to form a color print. Condensed working directions follow.[9]

Making the Black Prints.—Chromatone print paper is suitable either for contact or projection and should be handled only by an orange-yellow safelight as used for projection or bromide paper. When printing by contact, the light should be reduced so that the exposures may be more accurately timed.

The time of exposure required for a satisfactory print should be found first, the print being developed in the following developer for 1½ minutes at 65° F.:

Water	40 ounces	2 liters
Metol	15 grains	1.5 grams
Sodium sulfite (anhydrous)	½ ounce	22.5 grams
Hydroquinone	60 grains	6.5 grams
Sodium carbonate (anhydrous)	½ ounce	22.5 grams
Potassium bromide	25 grains	2.7 grams

If the grey scales of the other two negatives balance both in density and contrast, these may be exposed without further exposure tests, the exposure for the blue-sensation negative being increased by 25% and that for the red-sensation negatives by 15%. If the grey scales do not match, the time of exposure required to produce grey scales on all three negatives is determined first by test strips and the exposure for the blue and red sensation negatives increased 25 and 15 per cent respectively. The increase in exposure for these two negatives is necessary to compensate for the alteration in depth occurring in toning.

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[9] *Chromatone Printing,* Defender Photo Supply Company, Rochester, N. Y.

If prints are to be mounted with the collodion side up, printing should be done from the back of the negative to allow for the reversal of the image.

The prints should have a ¼ to ½″ margin to facilitate handling and should be marked on the back to indicate the negative and the time of exposure when made.

All three prints should be developed together for the same time. It is advisable to use fresh developer for each set of prints. The prints may be fixed in the usual acid fixing and hardening bath, but the following is recommended, as there is less danger of bleaching in toning:

Potassium thiocyanate	100 grams
Potash alum	50 grams
Water	1000 cc.
Glacial acetic acid	25 cc.

The prints are fixed for 15 to 20 minutes and washed for 15 to 20 minutes in running water. Ordinarily, the films separate from the paper backing in the fixing bath. The latter may be thrown away as it is no longer needed.

Toning.—The toning solutions are available ready for use upon dilution with water, from dealers or from the Defender Photo Supply Company, Rochester, New York. The solutions are prepared for use as follows:

(Sufficient quantity for toning 5 × 7 prints)

Red and Blue Toner A Working Solution:

Water	1 ounce	25 cc.
Red and Blue Toner *A*	1 ounce	25 cc.
Standard Ferricyanide Solution	1½ drams	5 cc.

This solution does not keep well when mixed, and only sufficient should be prepared for prints in process.

Yellow Toner A. Working Solution:

Yellow Toner *A*—No. 1	1 ounce	25 cc.
Yellow Toner *A*—No. 2	1 ounce	25 cc.
Standard Ferricyanide Solution (below)	1½ drams	5 cc.

In addition, the following solutions will be required for toning:

Standard Hypo Solution:

Granular or Rice Hypo	2¼ ounces	70 grams
Distilled water	32 ounces	1000 cc.

Wherever the text refers to Standard Hypo Solution, this is the formula that must be used. A bath containing acid or alum will bring complete failure.

Standard Ferricyanide Solution:

Potassium ferricyanide	½ ounce	11 grams
Distilled water	4 ounces	1000 cc.

The black and white prints from the green and red negatives are placed in the toning solution together and turned over and over to ensure uniform action of the toning solution. Toning requires about 15 minutes at 65° F., and should continue until all of the black silver image has been removed and a greenish brown image remains. The two prints are then washed for about ten minutes in running water.

The print from the green negative (to be toned magenta) is then placed in the Red Toner B for about ten minutes. (It proceeds to completion, therefore, a few minutes longer will do no harm.) The print is then fixed for three minutes in the standard hypo solution and washed 15 minutes in running water.

The print from the red filter negative (to be printed in blue-green) is placed in the blue toner B for ten minutes and then transferred to a bath of dilute hydrochloric acid for one minute. Finally, it is fixed in standard hypo solution until the greenish tones have changed to blue-green.

The print from the blue-sensation negative (yellow print) is immersed for ten minutes in the yellow toner A which must be prepared immediately before use. The toning solution is then poured off and standard hypo solution added as follows:

Yellow toner *A*	5 parts
Standard hypo sol.	1 part

The print is washed in water while this is done (not longer than one or two minutes) and again placed in the toning bath. The tray should be rocked vigorously to prevent streaking. After three minutes, the print is removed, washed one or two minutes in water and placed for one minute in:

Standard hypo solution	1 part
Water to	3 parts

As the image is soluble in hypo at this stage, it should not be left in the hypo bath longer than 1 minute.

Upon removing the print from the hypo, it should be washed twenty minutes in running water and placed for two minutes in yellow toning solution B, then washed a second time for twenty minutes.

The three images are now ready for assembling on Chromatone Backing Paper.

Assembling the Three-Color Images.—The backing paper is first soaked in water for several minutes and placed with the gelatin coated side uppermost on a sheet of heavy glass, masonite, or ferrotype tin.

The yellow image is placed on the paper first and squeegeed firmly into place, and allowed to remain for three or four minutes. The magenta image is then registered with the yellow, squeegeed lightly in place and the register checked. If adjustment is necessary, the film is stripped at once and reregistered, then squeegeed firmly into place. The blue-green image is the last to be added and in exactly the same way as the others.

Drying.—The print is left on the glass or ferrotype tin for ten to fifteen minutes, then gummed tape, 1 or 2 inches wide, is placed along all four edges so as to overlap the print from ¼ to ½ inch. This will hold the print flat while drying. When dry, the print can be removed by inserting a sharp knife through the tape under the edge of the print and cutting from the board.

Color Correction.—Any predominating color as shown by the grey scale or areas of the image which should be neutral, may be corrected in a later print by decreasing the printing time for that particular color. Naturally, if the print is light, better results may be obtained by increasing the exposure of the other two prints. For example, if the print shows a predominating yellow color in the grey scale or other areas which should be neutral, either the printing time of the print from the blue-sensation negative (yellow print) should be increased or that of the magenta and blue-green prints reduced.

The magenta and yellow images may be reduced in:

Hydrochloric Acid, C.P.	1 part
Water to	50 parts

Wash thoroughly when sufficient reduction has been obtained. The action of the hydrochloric acid on the yellow image is to reduce the finer details before affecting the depth of the image as a whole.

The blue image can be reduced by immersion in:

Red toner *B*	1 part
Water to	16 parts

until purple all over. Then place in:

Hydrochloric acid	1 part
Water	20 parts

until color returns. Finally wash thoroughly. As reduction tends to make the image greenish, it should be used only when absolutely necessary and with care.

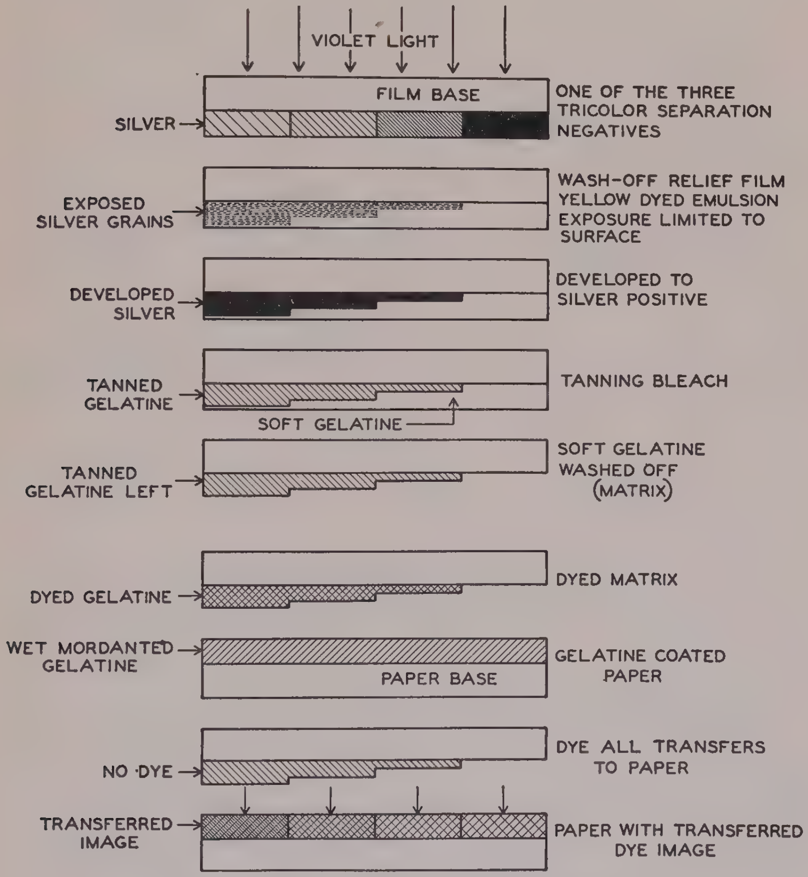
VIOLET LIGHT
FILM BASE
SILVER
ONE OF THE THREE TRICOLOR SEPARATION NEGATIVES
EXPOSED SILVER GRAINS
WASH-OFF RELIEF FILM YELLOW DYED EMULSION EXPOSURE LIMITED TO SURFACE
DEVELOPED SILVER
DEVELOPED TO SILVER POSITIVE
TANNED GELATINE
TANNING BLEACH
SOFT GELATINE
TANNED GELATINE LEFT
SOFT GELATINE WASHED OFF (MATRIX)
DYED GELATINE
DYED MATRIX
WET MORDANTED GELATINE
GELATINE COATED PAPER
PAPER BASE
NO DYE
DYE ALL TRANSFERS TO PAPER
TRANSFERRED IMAGE
PAPER WITH TRANSFERRED DYE IMAGE

FIG. 222. Diagram of Steps in Wash-Off Relief Process.

The Eastman Wash-Off Relief Process.—This process, developed in the laboratories of the Eastman Kodak Company, is an imbibition process which has achieved considerable popularity in the United States. Positives are made by contact or projection from the three-color separation negatives on Eastman Wash-Off Relief Film. The exposure is made through the film base so that the exposed portion of the emulsion is next to the base (Fig. 222). The emulsion is sensitive to blue and blue-violet only and contains a yellow dye, the purpose of which is to limit the penetration of the printing light so that the emulsion is not exposed through its entire thickness even in the deepest shadows. The exposed image is then developed, the resulting silver image (black in the diagram) varies in thickness almost directly in proportion to its density. The silver is then removed in a bleaching solution which hardens the gelatin in contact with the silver. The soluble gelatin is then removed by washing in hot water whence the name "Wash-Off Relief." The film is then fixed to remaining silver salts, washed and then immersed in the appropriate dye solution. The dye is absorbed by the relief image in proportion to the thickness of the gelatin. The dyed relief image is then placed on Eastman Imbibition paper, a gelatin coated paper, which has been treated with a mordanting substance so that the dye leaves the dyed positive and is fixed by the gelatin of the paper. The other two dyed positives are placed successively in contact with the paper in register with the first, to produce the color print.

The process is relatively simple, yet allows a considerable degree of control over results, is comparatively cheap in that duplicate prints may be made simply by redying the film positives, and is not overly sensitive to atmospheric conditions.

Making the Relief Positives.—Eastman Wash-Off Relief Film may be handled by an orange-yellow safelight such as the Wratten O or OA, if care be taken to avoid more than momentary exposure to the safelight.

The film is exposed through the support either by contact or projection. The exposure should produce well-modelled highlights with a slight veil when the unfixed films are viewed by reflected light from the support side after 5 minutes development in

	Avoirdupois	Metric
Elon	145 grains	10.0 grams
Sodium sulfite (des.)	4 ounces	120.0 grams
Hydroquinone	145 grains	10.0 grams
Kodalk	1 ounce 145 grains	40.0 grams
Potassium bromide	29 grains	2.0 grams
Water to make	1 gallon	4.0 liters

Use without further dilution.

The exposure required to produce a print of normal depth from the green-sensation negative, will be correct for all three negatives, if the scale of densities are alike. If the negatives do not balance exactly, the exposure for the other two negatives may be calculated from the difference in transmission of the maximum density, or by making separate test exposures on P.M.C. bromide paper.

In exposing the Wash-Off Relief film by projection, care should be taken not to make any adjustment or change which would affect the registration of the three images.

When exposed, the three wash-off relief films are developed for five minutes in the above Elon hydrochinon developer (DK–50) at 65° F. To avoid the necessity for handling the films during development (as the gelatin is unhardened and hence becomes soft) it is best to develop either in a tank with the usual cut film hangers or in separate trays.

After development, the films are washed for five to ten minutes in running water to eliminate all traces of the developer. Washing must be thorough or traces of developer left in the film will prevent the proper bleaching of the image.

Bleaching the Positives.—The films are then bleached in the following solution:

	Avoirdupois		Metric
Stock Solution A			
Water	16	ounces	500.0 cc.
Ammonium bichromate	290	grains	20.0 grams
Sulfuric acid, C.P. (E. K. Co.)	1	dram	4.0 cc.
Water to make	32	ounces	1.0 liter
Stock Solution B			
Sodium chloride (table salt)	1½	ounces	45.0 grams
Water to make	32	ounces	1.0 liter

For use: Take *A*—1 part; *B*—1 part, water—6 parts.

The white light may be turned on in the darkroom after the films have been placed in the bleaching solution. Two to three minutes are sufficient in most cases but the time should be sufficient to completely change the black silver image to a faint brownish image. The bleaching solution is discarded immediately after use.

The films are next transferred to separate trays containing water at 110° F. (43° C.) to dissolve the soluble gelatin. The trays are rocked for one minute, the films lifted successively by one corner and drained, then transferred to other trays containing water at the same temperature. This process is repeated four times or until the water draining from the film is clear and free of dissolved gelatin.

The reliefs are now placed for one minute in the following fixing bath:

	Avoirdupois	Metric
Water (about 125° F.) (52° C.)	80 ounces	2.5 liters
Sodium thiosulphate (Hypo)	2 pounds	960.0 grams
Sodium sulfite, desiccated (E. K. Co.)	2 ounces	60.0 grams
Acetic acid (28% pure) (E. K. Co.)	6 fluid oz.	190.0 cc.
Boric acid, crystals	1 ounce	30.0 grams
Potassium alum (E. K. Co.)	2 ounces	60.0 grams
Cold water to make	1 gallon	4.0 liters

Dissolve the chemicals in the order given.

Fixing is followed by five to ten minutes washing in running water after which the reliefs are hung up by one corner to dry. The reliefs dry rapidly and drying should not be hastened by heat or the film base may shrink resulting in faulty registration. Droplets of water on the film side may be removed with a cellulose sponge but the gelatin side should not be touched.

Dyeing the Reliefs.—The printing dyes are supplied in tubes making 500 cc. (16 ounces) of solution or in larger quantities and should be dissolved in boiling distilled water, the solutions cooled to 68° to 80° F. (20° to 27° C.) and filtered through rapid filter papers.

The trays used for the dye solutions should be free from chemical contamination of any kind. Glass trays are preferable but steel enamel trays are satisfactory if the enamel has not been chipped or badly etched.

The trays should be kept covered except when handling the films to prevent the access of dust and the evaporation of the solutions.

The relief from the red filter negative is placed in the blue-green or A dye solution, that from the green filter negative in the magenta or B dye solution and that from the blue filter negative in the yellow or C dye solution.

The trays containing the dye solutions should be rocked from time to time. About 30 minutes is required for dying at a temperature of 68° to 80° F. (20° to 27° C.) although longer immersion is without material effect if all three films are treated alike.

The dyes may be used again and again. Between use, they should be kept in tightly stoppered bottles away from strong light.

When dyed, the blue-green and magenta dyed reliefs are rinsed in two changes of a 1/10 per cent solution of acetic acid in distilled water and the yellow dyed relief in two changes of a ½ per cent solution to remove surplus dye from the surface, and set the dye taken up by the relief image.

The tray should be tipped up on one edge and the film placed in the tray with one edge immersed in the acetic acid. The tray is then quickly tipped in the opposite direction so that the solution sweeps quickly and uniformly over the entire surface. The tray is then rocked first sidewise and then lengthwise in alteration until the solution is uniformly tinted. In this way, streaks are avoided.

After rinsing, all three dyed reliefs are placed in a ½ per cent solution of acetic acid until needed for the imbibition transfer.

Inspection of Positives.—One of the important features of the Wash-Off Relief Process is that the reproduction of color in the final print can be determined quite well if the three dyed reliefs are superimposed on the bottom of a clean white tray so that any corrections necessary may be made on the reliefs before printing is begun.

If the negatives balance and are of suitable contrast, and the reliefs have been correctly exposed and developed, little or no corrective treatment should be required.

Corrective Treatment.—However, if the picture appears too flat, the reliefs should be rinsed in plain water to remove the excess acid and redyed for 30 minutes in a dye bath containing more acid. Experience only will indicate the amount of acid required in the dye bath. Increasing the amount of acid in the dye bath increases contrast, decreasing acid reduces the contrast of the dyed image.

To reduce contrast, the dyes should be removed from the reliefs by washing first in a 1 per cent of strong ammonia and then in plain water. The reliefs should then be redyed in a dye solution containing less acid.

Images which are too dense may be corrected by washing down the dyed reliefs uniformly in cold water, so as to remove some of the dye.

Table of Dilutions of Acetic Acid

Concentration in %	Amount of Acetic Acid	
	Glacial Acetic Acid	28% Commercial Acetic Acid
1/10%	1 cc. diluted to 1 liter, or ¼ fluid dram diluted to 32 ounces	3.6 cc. diluted to 1 liter, 1 fluid dram diluted to 32 ounces
½%	5 cc. diluted to 1 liter, or 1¼ fluid drams diluted to 32 ounces	18 cc. diluted to 1 liter, or 5 fluid drams diluted to 32 ounces
5%	50 cc. diluted to 1 liter, or 13 fluid drams diluted to 32 ounces	180 cc. diluted to 1 liter, or 5¾ fluid ounces diluted to 32 ounces

When the amount of reduction required has been attained, the relief is returned to the dilute acetic acid until the transfer print is made.

There is no remedy for matrices which have been underexposed.

Any prevailing tint in the highlights is the result of unbalanced exposure either in the negatives or the positives. It may be removed by washing the reliefs of the predominating colors briefly in water until removed. If, after the highlights have been corrected, a predominant tint remains in the half tones and shadows, the contrasts of the negatives are unequal. This may be corrected by washing and redying the reliefs of the predominating colors in dye solutions containing less acetic acid, or by redyeing the other reliefs in solutions containing more acid so that these colors will be strengthened to secure the proper balance.

Preparation of the Paper.—A special gelatin-coated paper is supplied as Eastman Imbibition paper. This is placed first in a mordanting solution prepared as follows:

	Avoirdupois	Metric
(*A*) Aluminum Sulfate (E. K. Co.)	6¾ ounces	200 grams
Water to make	32 ounces	1 liter
(*B*) Sodium Carbonate, Des. (E. K. Co.)	1 ounce 145 grains	40 grams
Water to make	16 ounces	500 cc.

Add B slowly to A, stirring well during the addition. A white precipitate is at first formed, but this dissolves upon stirring. If a trace should remain, it can be filtered out with a rapid filter paper.

After 5 minutes in the mordanting bath, the paper is washed 5 minutes and placed for 5 minutes in a 5 per cent solution of sodium acetate. It is then washed 5 minutes and dried, or may be used immediately.

Making the Imbibition Print.—The paper is placed, gelatin side upward, on a slightly larger sheet of plate glass. In order to stretch the paper to its maximum, so that it will not change during the imbibition transfer process and cause faulty register, a sheet of 0.005-inch Kodaloid is laid upon the paper, and a heavy squeegee wetted and drawn across the Kodaloid in both directions. Considerable pressure should be used on the squeegee. The paper is then laid on a damp blotter and the first dyed relief placed upon it immediately, before the paper has had time to dry.

The magenta dyed relief is placed image-side downward on the prepared paper. The two are held in place with the fingers of one hand, while the wet squeegee is run lightly across the film in both directions to expel water and air bubbles from between the relief film and the paper. Each successive stroke of the squeegee is with firmer pressure, and finally, the full pressure of the arm is brought to bear upon the squeegee to secure intimate contact. A second sheet of plate glass is then placed over the relief film to conserve moisture.

The relief is left in contact with the paper until substantially all of the magenta dye has transferred. From 10 to 30 minutes are required for the transference of the magenta dye, depending upon the shadow density. To determine whether or not sufficient time has been allowed, one corner of the relief is carefully lifted from the paper. Only a faint trace of dye should remain in the relief. If the time has been insufficient, more intense spots of dye will remain in the thicker portions of the relief, producing a mottle, while lighter spots will occur in the corresponding positions on the paper. Time must be allowed for these spots to disappear. The denser the shadows, the longer the time.

Transferring the Blue-Green Dye.—A sheet of 0.005-inch Kodaloid is wetted and laid upon the paper so as to cover the picture except for a margin of about one inch at the end toward the operator.

The blue-green relief is laid upon this Kodaloid, the end extending beyond the Kodaloid being held out of contact with the paper unless this area is completely occupied by a clear, safe edge. The relief is moved about until it registers accurately with the magenta image. The relief film is then brought into contact with the uncovered edge of the paper, and lifted completely off from the Kodaloid at its other end. The Kodaloid is then pulled, and the film is allowed to fall back into place on the paper. It is then squeegeed and covered with the plate glass as before. The time required for the transference of the dye is about the same as for the magenta dye, or from 10 to 30 minutes.

Transferring the Yellow Dye.—Finally, the yellow dyed relief is registered with the images already transferred, the thin Kodaloid being used in this operation as before. The relief is squeegeed and allowed to remain until the transfer is complete. The time required for the yellow is usually from 5 to 10 minutes.

Drying.—After removing the yellow relief, the paper bearing the three-color print is pressed between two dry blotters and dried at once in order to preserve the sharpness of the image.

Prints on glossy papers may be dried on ferrotype tins in the usual way.

Masking Methods.—One of the basic requirements of a dye or pigment suitable for a three-color subtractive printing process is that it should absorb one of the primary colors and transmit, or reflect, the other two. The ideal blue-green dye or pigment, for example, would absorb red but not green or blue-violet while the subtractive yellow would absorb blue-violet, but not green or red. Unfortunately, a set of pigments or dyes answering these requirements has not been discovered. There are a number of yellow dyes and pigments which are quite satisfactory, but practically all blue-green dyes absorb considerable green and blue-violet and the magenta dyes available absorb some blue-violet. As a result of these deficiencies in the dyes and pigments available for a subtractive color printing process, the colors of the reproduction are more or less unsaturated either through admixture with black, as in the case of the greens and blues, or through dilution with white, as in the case of the magentas, yellows and reds. It is difficult in many cases, therefore, to obtain the brilliant, saturated colors required for a good reproduction of the original. This is particularly true when the three color negatives have been obtained from a screen plate transparency in which case the degree of color saturation is already relatively low.

To overcome the deficiencies in the dyes used in the wash-off relief process, a method of color correction known as the masking method has been developed and patented by the Kodak Research Laboratories. The red filter negative is first made on wash-off relief film in the usual way. This film is then carried through the process in the usual way and dyed blue-green. When the dyed matrix has dried, it is placed in register with the green filter negative and the magenta positive exposed through the green filter negative and blue-green dyed matrix. The blue-green and magenta dyed positives are registered with the blue filter negative and a print made on wash-off relief film in the usual way. This positive is finally dyed yellow. Since the film is sensitive only to blue-violet light, the density of the yellow image is reduced in proportion to the density to blue-violet light of the magenta and blue-green images used as masks for the blue-filter negative. The blue-green and magenta images thus act as masks reducing the density of the yellow image in such a way that the correction desired is obtained automatically.[10]

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[10] For detailed directions of the masking method, see *Color Prints from Kodachrome Films,* by Kurtzner and Seymour, *Amer. Phot.,* 1937, 208.

Three Color Carbro.—The carbon process was for a long time the only really practical means of printing from three color negatives. In recent years, it has largely been superseded by three color carbro. Three color carbro, while more exacting in its technique than other processes in general use, in capable hands is still unsurpassed. The procedure, in general, is the same as monochrome carbro (see Chapter XXV) except that the trichrome tissues are employed and the pigment images developed on celluloid and then transferred to a gelatin coated paper which forms the final support. Condensed working directions follow.[11]

Making the Bromide Prints.—A smooth surface bromide paper without a supercoating should be used. It is preferable to purchase the paper in rolls and cut the sheets in the same direction to avoid differences in the expansion of the paper which would affect the registration of the three images. The prints may be made either by contact or projection and should be fully developed using the developer recommended by the manufacturer of the paper. The grey scales on all three prints should balance and each print should have a narrow white margin.

After fixing and washing, the prints should be placed in a 2 per cent solution of acetic acid for two minutes to facilitate the removal of any lime which may have been absorbed from the water used for washing. Finally, the prints should be swabbed with absorbent cotton, washed for five to ten minutes in running water. The backs of the prints should be marked for identification; blue-green, magenta and yellow.

Preparing the Celluloids.—The sheets of celluloid on which the pigment images are developed should be at least two inches (5 cm.) larger in each direction than the prints and about 1/50 inch (½ mm.) thick. Before use, the celluloid sheets are first waxed, the special wax being applied with a soft lintless cloth soaked in gasoline and polished with a dry cloth. Unless the excess of wax is removed in polishing difficulty will be experienced in development. After polishing, the celluloid sheets are dipped into a bichromated solution of albumen prepared as follows:

Beat the white of one egg to a froth and add 15 ounces of water. Dissolve separately in 5 ounces of water, 150 grains of potassium bichromate and add to the albumen solution. Filter through cheese cloth and store in a dark place.

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[11] *Trichrome Printing by the Autotype Carbro Process.* Autotype Company Ltd., London.

Upon removal from the albumen solution, the celluloid sheets are rinsed in water and dried in daylight or in strong artificial light. The albumen treatment provides a better base for the pigment paper and lessens frilling and loss of highlight detail.

Sensitizing Formulas.—

Stock Solution "A"		
Potassium ferricyanide	1 oz.	50 gm.
Potassium bromide	1 oz.	50 gm.
Distilled water	10 oz.	500 cc.
Stock Solution "B"		
Potassium bichromate	180 gr.	20 gm.
Chromic acid	40 gr.	4.5 gm.
Chrome alum	100 gr.	11 gm.
Distilled water	10 oz.	500 cc.

Hot water must *not* be used in compounding the stock solution "B."

The Working Baths.—These are made up as follows:

No. 1 Working Bath	
Stock solution "*A*"	1 part
Water	4 parts
No. 2 Working Bath	
Stock solution "*B*"	1 part
Water (boiled or distilled)	4 parts

The No. 1 bath may be used for a considerable number of prints, but the No. 2 bath should be renewed after each set (of 3) as it is altered by the No. 1 solution transferred to it.

The baths should be used at a temperature of 60° to 65° F. (15° to 18° C.).

Making the Carbro Prints.—The three pigmented papers required for three-color carbro are supplied by the Autotype Company of London as Autotype Trichrome Pigment Papers. As in other subtractive processes, the yellow print is made from the blue-sensation negative (i.e., the bromide print from the blue-sensation negative), the blue-green print from the red sensation negative and the magenta print from the green sensation negative. The pigment papers, however, are termed yellow, blue and red by the Autotype Company.

The pigment papers should be approximately one inch (2.4 cm.) larger in both dimensions than the bromide prints. The pigment papers are first immersed for two minutes in the No. 1 bath, then placed face down on a sheet of clean glass and squeeged to remove the surplus solution. The contrast of the pigment image is controlled by the time of immersion in the second bath—the longer the time of immersion, the lower the contrast. The usual range is from 20 to 40 seconds with 25 seconds the average for bromide prints of good quality.

The bromide print, which should have been soaking in water, is placed face up on a sheet of glass, the pigment paper, held by opposite corners, is lowered into contact with the bromide print. It is then squeegeed first in one direction and then the other, care being taken not to shift the position of the pigment paper, or a blurred image will be produced.[12]

After ten minutes, the pigment paper is stripped from the bromide print and placed for one minute in a solution of equal parts of denatured alcohol and water. The bleached bromide print is washed in running water 10 to 15 minutes and redeveloped after which it may be used again.

The pigment image is now ready to be transferred to the waxed celluloid sheet. The celluloid sheet is swabbed with a tuft of wet absorbent cotton to remove any adhering dust and the pigment paper squeegeed firmly to it.

Precisely the same treatment is given the other two pigmented papers.

Development of the Carbro.—To avoid frilling, a weak solution of chrome alum is used for developing (i.e., dissolving the soluble gelatin) rather than plain water. A stock solution is prepared as follows:

Chrome alum..............................	300 gr.	30 gm.
Water to..............................	10 oz.	400 cc.

For use, ¼ oz. (12 cc.) of this stock solution is added to each 16 oz. (1000 cc.) of water at 105° F. (40° C.).

The method of development particularly recommended is to hold the celluloid in both hands with the pigment paper underneath, and bending slightly, so that the latter is on the outside of the curve press down into the water so that the paper backing enters first, and after a few seconds turn the celluloid over and completely submerge.

When the pigment commences to ooze out from the edges, this is the signal for the backing paper to be stripped away very carefully from the celluloid, during which operation, the print must be kept under the water. The celluloid, still under water, is then shaken with a lateral movement and occasionally lifted out until no color can be seen running from it. It is then given a rinse in cold water and placed to dry, all surplus water being removed from the back. The other two are treated in a similar manner.

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[12] A special press has been introduced which brings the bromide print and the pigmented tissue into contact without danger of shifting. (George Murphy Inc., 57 East Ninth Street, New York City.)

Transfer from Celluloid to Soluble Temporary Support Paper. The Blue Print.—A piece of Soluble Temporary Support paper is soaked face downwards in a dish of cold water for about five minutes in order that it may fully expand. The dish should be rather larger than the celluloids being employed. The dry blue-green Carbro image on the celluloid is slid beneath the paper and the two withdrawn together and squeegeed into contact, forming a " sandwich," which, after blotting off all surplus moisture from back and front, is pinned up to dry. When perfectly dry, it will be found that the paper can be stripped from the celluloid with the image transferred to it. The celluloid is then ready for rewaxing and further use.

The film of wax with which the celluloid was prepared will also have been transferred to the surface of the Carbro print on the paper, and this wax must now be carefully and thoroughly removed, by rubbing it with a wad of cotton wool saturated with gasoline. The gasoline and dissolved wax is then polished off quickly before the gasoline evaporates with a piece of soft cloth, and to ensure complete removal, the operation should be repeated, using methylated spirit.

Combining the Blue and Red Print.—The Soluble Temporary Support bearing the blue-green image is soaked now in cold water for about two minutes, and the celluloid bearing the dry magenta image slid underneath it, the two are withdrawn, moved into rough register and very slightly squeegeed into contact. This " sandwich " is then placed on a sheet of blotting paper, celluloid uppermost, and moved into exact register. The paper is squeegeed again, but somewhat heavier than before, care being taken not to spoil the registration. Should movement have taken place, return to the water, carefully strip off and re-register.

The Yellow Print.—The blue-green and magenta " sandwich " is again dried, and after removing the wax, as previously described, the yellow print is treated in a similar manner.

Transfer to Final Paper.—A piece of Single Transfer paper, rather larger than the temporary support, is soaked for ten minutes in cold water. When the three combined images have been stripped from the last celluloid and the wax removed, it is soaked in water for about one minute and squeegeed into contact with the single transfer paper. The two are placed between blotting boards under light pressure for ten minutes, after which they are immersed in a dish of water at about 105° F. (40° C.), and after a few moments, the Temporary Support is peeled off. A coating of soluble gelatin, though invisible, is left in the surface of the print, and this is removed by gently laving with the hot water. The finished print is then chilled in cold water and hung up to dry.

Ives Polychromide Process.—This is a subtractive process developed by F. E. Ives for printing from two-color negatives but although only two prints are made, three colors are used as in trichromatic processes. This result is obtained by making a dichroic (two-color) red-to-yellow-print (red in the shadows, orange in the halftones and yellow in the highlights) on film from the green sensation negative and superimposing this image on a blue-toned bromide print made from the red-sensation negative. These prints may be made from the original negatives either by contact or by projection.

The print from the red sensation negative is made on ordinary bromide paper which is then toned blue by means of an iron toning solution. The print from the green sensation negative is made on Eastman Wash-Off Relief film, the image bleached, and the soluble gelatin removed by washing in hot water, thus producing a gelatin relief image. This relief image is then dyed in the following dichroic toning solution:

The formula of the dye bath is as follows:

Moderately hot water	1 gal.	3¾ liters
Carmoisine *C*—Sandoz	10 grains	0.648 gram
Azo-Rubine *S*—Sandoz	30 grains	2 grams
Metanil Yellow—Sandoz	40 grains	2.6 grams
Glacial acetic acid	1 ounce	30 cc.
Citrate of potash	2 to 4 ounces	56 to 112 grams

Approximately five minutes is required for dyeing the gelatin relief but a longer immersion increases the characteristic dichroic effect, thus increasing the brilliancy of the yellow and green. Red is taken up rapidly—in from two to three minutes—but with longer dyeing the yellow replaces the red in the halftones and highlights, producing the dichroic red to yellow image. The amount of dyeing is controlled by the amount of potassium citrate used. A large amount of potassium citrate makes prints lighter. A print which is too strong can be reduced by washing in water, while a weak image may be intensified by immersion in a dye bath containing less potassium citrate.

When the dye image has reached the desired strength, the film should be removed and placed in a weak solution of acetic acid to prevent any running of the dye, after which it is hung up to dry. When dry, the two prints are superimposed, the images registered and attached to one another along one edge with a piece of adhesive tape. A solution of amyl acetate is then applied to the back of the film and the two images cemented together.[13]

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[13] Ives, *Camera* (Philadelphia), 1933, 33. *Brit. J. Phot.* (Color Supplement), 1933, 29.

CHAPTER XXIX

SCREEN PLATE PROCESSES OF COLOR PHOTOGRAPHY

Introduction.—The screen plate processes are comparatively simple to work and until recently were virtually the only processes of natural color photography practical for the average amateur or professional photographer. The greatest disadvantage of the screen plate processes is that they are incapable of producing prints on paper except by the rather lengthy and laborious process of making three-color separation negatives from the transparency and prints from these negatives by one of the subtractive printing processes. Another disadvantage is the limited range of brightnesses over which the screen plate processes are able to reproduce color satisfactorily which places a restriction on the subject matter suitable for the process. While more marked in some processes than others, this is a necessary consequence of the fine-grain, thinly coated emulsion used to obtain sufficient resolving power to sharply define the fine color elements of the screen. The pattern formed by the screen is an objection in many cases as when the image is to be enlarged or when critical definition is required. Lastly the screens involve a great loss of light so that the image is dark unless a powerful source of light is used for illuminating the transparency or for projection.

The Requirements of a Screen Plate.—The following factors determine the performance of a screen plate:[1]

1. *The size of the color-elements.* These must be below the resolution of the eye (visual angle of 1 minute, corresponding to 0.02 mm. at the average distance) but above the resolution of the emulsion. If too large, the elements are perceived individually; if too small the color rendering cannot be truthful since the emulsion is unable to record accurately the result produced by the screen.

For geometric screens, the color elements should not be larger than 1/300 of an inch or much smaller than 1/600 of an inch; for mosaic screens the size should not exceed 1/900 of an inch or be less than 1/2000.

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[1] Mees, 1. *J. Chem. Ed.,* 5 (1928), 1578.

The color elements may be larger in a geometrical screen than in a mosaic because in the latter it is virtually impossible to avoid a certain amount of clumping on the part of color-elements of the same color thus giving rise to areas producing a dominant color.

2. *The transmissions of the color elements.* The requirements of the three-color taking filters have been discussed previously (p. 529). The transmissions of three-color viewing filters, unlike the taking filters, should not overlap and should be relatively narrow so as to produce brilliant, sharply defined colors (F. E. Ives). In a separate screen process, the transmissions of the filters of the taking and viewing screens need not be the same, although of course, the color elements must be of the same size in both screens and must conform to the same pattern. In a combined screen plate process, such as Dufaycolor, Autochrom, etc., the same screen must serve both for taking and viewing; the transmission of the color-elements must represent the best compromise possible under the circumstances.[2]

3. *The relative area covered by each color.* This must be adjusted so that the screen appears neutral.

If the screen as a whole possesses a dominant tint obviously it cannot reproduce colors correctly but must result in a distortion of the colors of the original in the direction of the dominant color of the screen.

4. *The interstices.* These, if they exist, must be filled to prevent irradiation, which would greatly reduce the ability of the emulsion to image the color-elements sharply.

5. *Thickness of the screen.* The screen must be as thin as possible to prevent parallax. The thickness should not in any case exceed the smallest dimension of the color elements.

6. *The emulsion.* This must be panchromatic, highly and as evenly sensitive as possible. If the emulsion is not equally sensitive to the light transmitted by the three filters of the screen, a color filter must be used over the lens in order that equality of action may be secured through all three filters. Its resolution must be equal to the color-elements of the screen and it must be able to produce a relatively high density in order that where necessary the color-elements which should not function in the formation of an additive color can be stopped out. In the case of a screen-plate in which the screen and the emulsion are

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[2] Mees, *Brit. J. Phot.*, **55** (1908), 41; **58** (1911), 45, 52, 62, 68 (col. suppl.).

inseparable, the emulsion must be adaptable to the requirements of the reversal process.[3]

The Lumière Filmcolor.—The first commercially successful screen plate was the Lumière Autochrom introduced commercially in 1907.

The screen (Fig. 223) is composed of grains of potato starch about 15/1000 millimeter (.0024 inch) in diameter, colored orange, green and blue-violet. The grains of potato starch are first passed through a sieve to obtain a uniform grain size and then divided into three groups each of which is dyed. The grains are then mixed thoroughly (in the ratio of 4 green to 3 red and 2 blue) to secure even distribution of the different colored grains and then dusted on film base which has been coated previously with a suitable substratum. The interstices are filled in with a fine powder and the layer smoothed out by rolling with heavy pressure. The screen is then covered with a thin layer of waterproof varnish over which is coated a panchromatic emulsion. The screen is not white but a light salmon pink and transmits approximately 7.5 per cent of the incident light.[4]

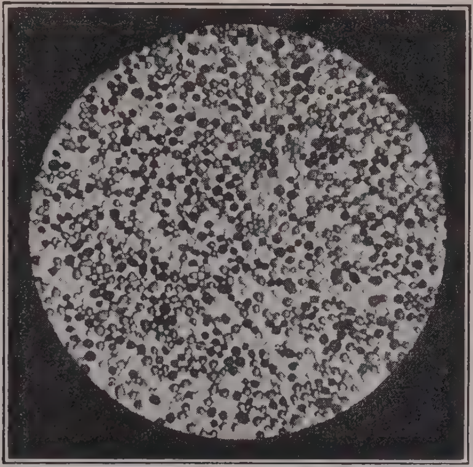

FIG. 223. Photomicrograph of the Autochrome Screen

In 1932, the Autochrom screen was supplied on film under the trade name Filmcolor. The original Autochrom plates on glass have since been discontinued.

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[3] Thorne-Baker, *Phot. Jl.*, **72** (1932), 109.

[4] Ventujol, "Manufacture of the Autochrom Plate," *Amer. Phot.*, **18** (1924), 384.

The film may be used in the usual cut film holders, but is loaded with the film side facing the lens so that the multicolor screen is nearest the lens and in front of the sensitive emulsion. Owing to the thinness of the film base, no correction in focusing is necessary for the reversal of the film in the holder.

Filters are available for sunlight, incandescent and photoflood lamps. Using a Weston meter, the exposure in daylight is twelve times the exposure required for a film or plate with a rating of 8 or 3 with incandescent tungsten or photoflood illumination.

Processing involves three operations: (1) development of the negative image, (2) dissolving the developed silver image, and (3) second development (of a positive image).

The developer is prepared as follows:

Distilled water.................	35	oz.	or	1.000 cc.
Metoquinone (Quinomet).......	½	oz.	or	15 grammes
Anhydrous soda sulfite..........	3½	oz.	or	100 grammes
Ammonia 920 (22° Baume)......	9	drams	or	32 cc.
Pot. bromide..................	240	grains	or	16 grammes

The metoquinone powder should be dissolved first in two-thirds the quantity of water, which is heated to the boiling point. After the metoquinone is thoroughly dissolved, add the other chemicals in the order given, adding the other one-third of cold water just before the ammonia is added. For use take:

Stock solution..................................	1 part
Water..	4 parts

The factorial method of development (see p. 303) is recommended using a factor of 10. A dark green safelight of the type used for panchromatic film may be used to follow the appearance of the image.

After development, the film is rinsed briefly in water and placed in the following solution and exposed to white light:

Potassium bichromate..................	30 gr.	2 gm.
Sulfuric acid, C.P......................	3 dr.	10 cc.
Water to.............................	32 oz.	1000 cc.

In this solution, the silver of the negative image dissolves the film becoming clear in from 3 to 4 minutes in daylight or 5 to 6 minutes by artificial light. All the silver of the negative image must be removed or black spots and streaks will appear in the development of the positive image.

After clearing, the film is rinsed briefly in water and placed again in the developer, which should have been kept for this purpose. Development will require from 3 to 5 minutes and must be carried to completion. Overdevelopment is not to be feared. In this operation, a positive image appears in full color. Finally, the film is washed for two or three minutes in running water and dried. There is no fixation.

Agfa Ultracolor Plate.—This mosaic screen is made from dyed particles of gum arabic rolled out in collodion. The size of the color elements are about the same in the Agfacolor screen as in the Autochrom but are more uniform varying from 0.008 to 0.017 millimeter.[5] The screen, however, transmits nearly twice as much light as the Autochrom, the relative transmissions being 14 and 7.5 per cent respectively.

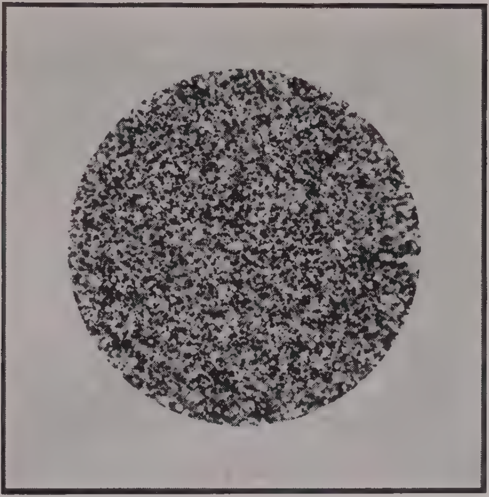

FIG. 224. The Agfacolor Screen

Since the Agfa Ultracolor screen is on glass and the plate must be loaded with the glass side towards the lens, a correction is necessary in focusing to compensate for the displacement of the sensitive emulsion. This compensation can be made in one of four ways:

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[5] Pledge, *Brit. J. Phot.*, 70 (1923), 48 (Color Supplement).

1. Reversing the ground glass, placing the ground surface to the rear away from the lens.
2. Racking the lens back—or the back of the camera forward—a distance equal to the thickness of the glass plate—approximately 1/16 inch.
3. Placing the usual glass filter behind the lens. This method permits the use of a focusing scale in the usual manner.
4. Using a special filter, such as the Zeiss "A" Ducar, which is a weak negative lens and lengthens the focal length of the camera lens sufficiently to compensate for the thickness of the glass plate.

No filter is required with the Agfacolor ultra plate when exposed in daylight; the Agfa No. 24 (blue) filter is required with incandescent tungsten, photoflood or photoflash lamps.

Processing as in other combined screen plate processes involves: (1) first, or negative, development, (2) reversal or removal of the negative image and (3) redevelopment or development of the positive image. The following developer is used:

Water	32 oz.	1000 cc.
Agfa metol	48 gr.	3.3 gms.
Agfa hydroquinone	15 gr.	1.0 gms.
Agfa Ansco sodium sulfite, anhydrous	¾ oz.	25.0 gms.
Potassium bromide	22 gr.	1.5 gms.

Cool to room temperature and add 2 dr. (7.5 cc.) of ammonia, specific gravity .91, ammonia content 25 per cent by weight.

This stock solution is for use diluted with equal parts of water (1 part stock solution to 1 part water). About 2 ounces of the dilute solution is sufficient for one 3¼ × 4¼ plate. Since the bath loses energy in development and is later rendered impure by re-development in it of the reversed plate, every plate must have fresh developer for the first development, and the temperature as used should not be allowed to exceed 65° F. This is very important especially in summer, as too warm a bath develops too quickly and spoils the film by melting and bubbling.

The use of desensitizers is not recommended by the Agfa Company owing to the difficulty experienced in determining the proper time of development in a reversal process; however, if desired, the plate may be desensitized in a solution of Pinakryptol yellow (1:1000), which must be used as a preliminary bath and not as an addition to the developer. After an immersion of three minutes in the desensitizing solution, the plate may be developed in a bright red light such as is used for ordinary (blue-sensitive) emulsions. The factorial method, however, cannot be used as the factor is altered by desensitizing.

With correct exposure, the time of development is 4 minutes at 65° F. (C.).

After development, the plate is rinsed briefly and placed in an acid solution of potassium bichromate prepared as follows:

Potassium bichromate	1 oz.	340 gr.	53 gm.
Sulfuric acid (C.P.)	3¼ oz.		100 cc.
Water to	32 oz.		1000 cc.

For use take:

Stock solution	1 part
Water	10 parts

After one minute, the plate should be exposed to white light, either daylight or strong artificial light such as that provided by a Photoflood lamp.

When the negative image is completely dissolved, the plate is rinsed briefly and redeveloped in the same solution used for first development. Redevelopment must be to finality and ordinarily requires approximately 2 minutes.

After development, the plate is washed for two to three minutes and then dried as rapidly as possible without, however, the use of heat.

Dufaycolor.—This process, unlike the two previously discussed, employs a geometrical type screen or *reseau* (Fig. 225).

The acetate film base is first coated with a very thin layer of collodion dyed blue; this is followed by printing a set of greasy ink lines with engraved rollers at an angle of 90 degrees to the length of the roll, there being 20 lines to the millimeter and the interspaces being equal in width to the lines. In the next operation, the dye between the ink lines is bleached and a green dye colors these clear spaces. The ink is dissolved and a series of blue and green parallel lines covers the entire film base.

A second set of ink lines is now printed at right angles to the first. The lines this time are broader than in the first instance and the spacing narrower but there are the same number per millimeter as before. The second bleaching bath removes the green and blue dye where there is no protecting ink and the spaces are dyed red. The ink resist is removed, resulting in a microscopic regular pattern of green and blue squares with red lines in absolute juxtaposition. The reason for having the red lines narrower is to equalize approximately the areas of red, green and blue. A protective varnish is coated over the screen to prevent desensitization of the highly panchromatized emulsion used.

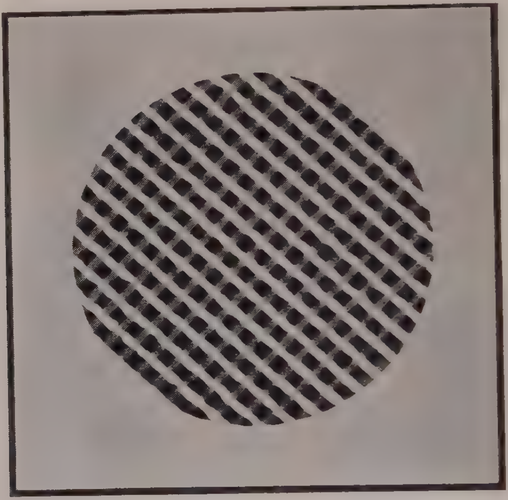

FIG. 225. The Dufaycolor Screen

The spectral transmission of the dyes is wider than that of standard trichromatic filters and this gives a higher overall transmission than would otherwise be obtainable.

Dufaycolor Reseau Transmissions[6]

Blue up to 530 millimicrons.
Green between 470 to 620 millimicrons.
Red from 570 millimicrons.

Dufaycolor material has a speed approximately one-half that of commercial black and white panchromatic film, having a Weston rating of 8 with daylight and 3 with incandescent tungsten, so that it lends itself to all classes of color photography and the panchromatization is such that excellent results are obtained without filters in daylight, though for accurate reproduction especially of green foliage a special filter is recommended.

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[6] Thorne-Baker, *Phot. Jl.*, 72 (1932), 112.

Processing is carried out by the reversal method, the constituents of the first developer being somewhat different to the usually accepted type of reversal formula. Potassium thiocyanate is used as the silver bromide solvent instead of the usual ammonia and the bath, therefore, has a considerably longer life.

Development should be conducted in total darkness or at a considerable distance from a safelight fitted with a Wratten Series 3 safelight or its equivalent. The following developer is recommended:

Metol	1 gram	16	grains
Hydroquinone	8 grams	128	grains
Sodium sulfite (des.)	50 grams	1¾	oz.
Sodium carbonate (des.)	35 grams	1¼	oz.
Potassium bromide	5 grams	80	grains
Potassium thiocyanate	9 grams	144	grains
Water	1000 cc.	35	oz.

The films may either be developed by inspection or the time and temperature method, the developing times for correct exposures being as follows:

65° F.	5 minutes
68° F.	4½ minutes
72° F.	4 minutes
75° F.	3 minutes

Full advantage of visual inspection is obtained by desensitizing in a 1:2000 solution of Phenosafranine for 2 minutes and development carried out with a suitable safelight such as the Wratten OA, with a low-wattage bulb, providing the film is not exposed to the light for prolonged periods. The film is viewed by reflected light and the highlights should be developed until the image appears brilliant and full of detail.

After developing, wash one minute in running water. The developed image is then removed in the following bath:

Potassium bichromate	5 grams	48 grains
Sulfuric acid (commercial)	10 cc.	96 minims
Water to make	1000 cc.	20 oz.

About four minutes will be required to completely remove the developed silver image. The reversed image should then be clearly visible. Wash for two or three minutes and then place in the following clearing bath for two minutes:

Sodium bisulfite	25 grams	240 grains
Water to make	1000 cc.	20 oz.

After clearing, wash for two or three minutes in running water.

In order to render the silver halide remaining developable it is necessary to expose the film to light before redevelopment. An exposure of one minute at a distance of 12 inches from a 100 watt bulb is usually sufficient. Additional exposure, however, within reason, will do no harm.

Any good metol-hydroquinone developer may be used for redevelopment, but the following is recommended:

Metol	1 gram	9.6 grains
Hydroquinone	5 grams	48 grains
Sodium carbonate (des.)	20 grams	336 grains
Sodium sulfite (des.)	50 grams	480 grains
Potassium bromide	1 gram	9.6 grains
Water to make	1000 cc.	20 oz.

Time of development: 3 to 4 minutes at 65° F. Overdevelopment is not to be feared. After a short rinse in water, the positive should be fixed for three minutes in the following fixing bath:

Hypo	360 grams	14 oz.
Potassium metabisulfite or sodium bisulfite	12 grams	½ oz.
Water to make	1000 cc.	40 oz.

Dissolve separately and add:

Chrome alum	40 grams	160 grains
Water to make	1000 cc.	35 oz.

Finally wash for 15 minutes. Dry as rapidly as possible, but do not use heat.

Weak images lacking in brilliancy may be intensified with chromium or mercury. Dense positives may be reduced in weak Farmer's Reducer.

Sources of Failure with Combined Screen Plates.—

Fault	Cause	Remedy
Image lacks density	Overexposure or overdevelopment	Intensification
Image weak and transparent particularly along the edges	Overdevelopment	Intensification
Image dense or with excessive contrast	Underexposure or underdevelopment	Reduction in a subtractive reducer followed, if necessary, by intensification.
Image with satisfactory detail but colors dull	Underdevelopment	Same as above
Image shows trace of negative image	Insufficient bleaching.	None
Image shows black mottling	Insufficient bleaching	None
Image is in complementary colors	Fixed after first development	None
Image shows no color......	Exposed with emulsion facing the lens	None
Blueness of image	Insufficient exposure or development (Autochrom) Filter omitted when making exposures by daylight (Autochrom)	None
Brownish stain	Incomplete bleaching	None
Frilling	Processing at a temperature above 60° F. (15° C.) or using solutions at different temperatures	
Image is not sharp	Failure to allow for thickness of glass when using Agfa ultracolor plates	None
General greenish cast Image lacking in contrast	Fog from exposure to green safelight lamp. Occurs only if exposure is made *through* the screen	None

Varnishing and Binding of Screen Plate Transparencies.— While not absolutely necessary, it is advisable to protect screen plate transparencies by varnishing or by binding between glass. Varnishing has the added advantage of increasing the transparency of the colors. A suitable varnish may be obtained commercially or may be prepared by dissolving three parts of gum dammar in 1000 parts of benzol.

Transparencies on glass may be coated by pouring a small quantity of the varnish in the center and then tipping the plate slightly towards each corner in succession until the surface is evenly covered. The excess varnish may then be allowed to run from one corner into the bottle. If any of the varnish runs over on the glass size, it may be removed with a solution of benzol.

The simplest method of dealing with film transparencies is to pour a small quantity of varnish in a tray of suitable size, immerse the film completely, and hang up with a clip from one corner. The film should be allowed to dry suspended from the same corner by which it was lifted from the varnishing solution, otherwise the varnish may flow back over itself producing ridges or areas with a double thickness of varnish.

Many prefer to bind screen plate transparencies between glass, using strips of gummed paper in the same manner as when binding lantern slides. If desired, a sheet of fine etched ground glass may be used to diffuse the light. The ground side should be placed on the outside so that the granularity will not interfere with the image.

Viewing and Projecting Screen Plates.—Screen plate transparencies may be mounted on illuminators or in viewing devices of which Fig. 226 is an example. Since the transparencies are de-

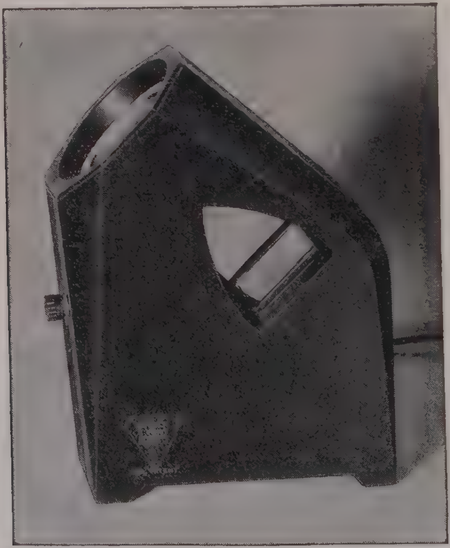

Fig. 226. Viewer for Color Transparencies. (Bausch & Lomb Optical Co.)

signed to be viewed by light of daylight quality, either a daylight blue lamp, or better still, a clear glass bulb with a suitable daylight filter, should be employed.

By far the best means of displaying screen plate transparencies, however, is by projection. The amount of light absorbed by screen plates necessitates a projector with a more powerful source of light than is required for black and white lantern slides or a smaller projected image. A projector with a 250 to 500 watt lamp is desirable although a 100 watt lamp may give satisfactory illumination with a good screen and if the image is small. Screen plates are quite sensitive to heat and to avoid possible damage, only well ventilated projection equipment should be used. Projectors with high wattage lamps should be fitted either with a cooling system or have a heat absorbing cell between the light source and the condensing lenses. In any event, it is well not to leave the slides in the carrier longer than absolutely necessary.

Duplication of Screen Plates.—Copies of screen plate transparencies on film may be made by contact printing on another screen plate while glass transparencies may be reproduced by copying in the camera. Copies, however, are less brilliant than the original because of the increased silver in the image and the dilution of the colors of the original with light of other colors.

In order that the emulsion beneath the red filter elements, for example, of the screen plate on which the copy is being made may be rendered developable, it is necessary that they be directly beneath the red filter elements of the transparency which is being copied. Except in the case of screen plates having a regular pattern, it is impossible to register the two screens so that the filters of any one color in one screen are directly in line with those of the other. Thus, it is only at

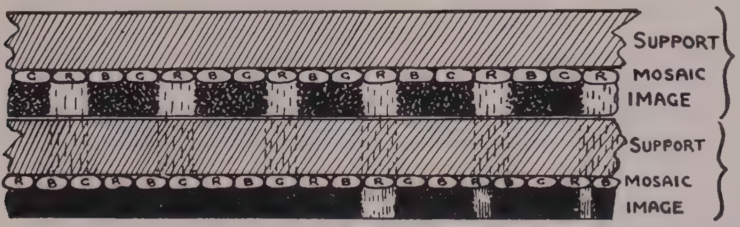

FIG. 227. Increase in Proportion of Black When Copying by Parallel Light. (Spencer, Photographic Journal. 1933)

points where two filters of the same color happen to be in line that any effect is produced in the copy (Fig. 227). It is evident, therefore, that the number of filter elements of any one color which are made developable will be much less than in the original transparency and that upon reversal the proportion of black silver in the positive copy will be greater than in the original, thus degrading the color.

A further source of degraded colors arises from the scatter of light by the silver particles of the image. This scatters the light transmitted by the red filter elements, for example, and forms a halo of exposed silver halide particles in the immediate vicinity of the filter element (Fig. 228). After reversal of the image to a positive this forms a clear halo around the red filter element through which light from adjoining blue and green filter elements is transmitted along with the red light transmitted by the red filter element, thus lowering the saturation of the color. Irradiation affects to some extent the saturation of the colors of a screen plate transparency made direct from nature, the loss is increased by duplication becoming an important factor in the quality of the duplicated transparency.[7]

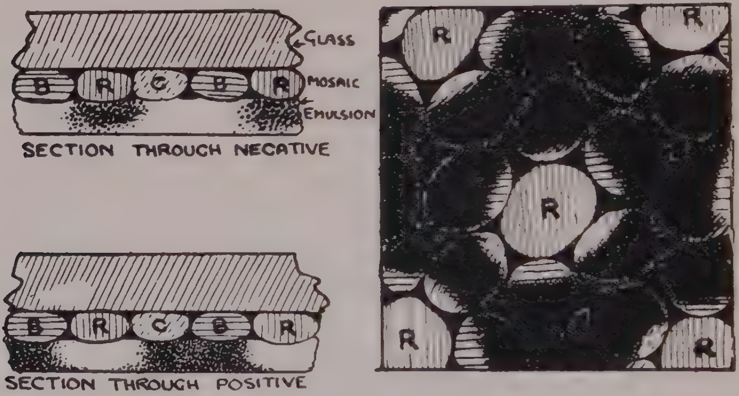

Fig. 228. Loss of Saturation Through Irradiation in the Emulsion. Courtesy of Spencer, Photographic Journal

The Finlay Process.—The Finlay process, unlike those already discussed, is a separate screen process, that is to say the screen and the emulsion are on separate glass plates which are placed in contact in a suitable holder for the exposure.

[7] These illustrations are from "Reproducing Screen Plates," by D. A. Spencer, *Phot. Jl.*, 73 (1933), 19.

The screen (Fig. 229) is composed of red, green and blue color elements approximately 1/300 of an inch square. It is made by printing in dyed bichromated[8] albumen from a black and white cross-lined screen. The glass plate is first coated with collodion containing a tricolor green dye. It is then coated with bichromated albumen and exposed beneath the cross-ruled screen. The areas not protected by the insoluble albumen are bleached out and dyed with a tricolor red dye. The plate is coated with albumen a second time and exposed beneath a cross-lined screen so as to render the bichromated albumen insoluble over the red color areas, the unprotected areas bleached and dyed with the tricolor blue dye.

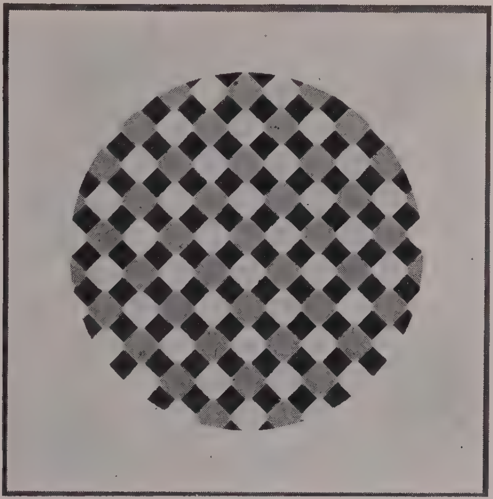

FIG. 229. The Finlay Screen

Finally a protective layer of collodion is placed over the whole.

As the screen and the sensitive material are separate, a special plate holder with a pressure back must be used to ensure perfect contact between the screen and the sensitive emulsion. Suitable holders may be obtained from the Finlay Company or its dealers. The taking screens may be used over and over if care is taken to avoid marking the surface but one must have a separate screen for each plate holder. Four filters are available for use over the lens with the Finlay-Eastman panchromatic plate; No. 4508 for use in sunlight, No. 4525 for use on cloudy days or in the shade; No. 4600 for tungsten lamps and No. 4547 for Photoflash lamps.

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[8] Stobart, *Phot. Jl.*, **76** (1936), 280.

Exposure and Development.—The Finlay process requires approximately six times the exposure of a hypersensitive panchromatic material. The Weston speed to daylight is 6; to tungsten illumination 4.

It is important that the color registering scales at the ends of the taking screen are properly recorded on the negative. This must be done before the exposed negative has shifted position on the taking screen. If the subject is not well lighted, at the ends of the plate, so as to propertly expose the color scales, it is necessary to expose them separately. This can be done immediately after the regular exposure by inserting a dark slide which has slots cut out over the color scale.

Any good, soft-working developer may be used; Metol hydroquinone formulas such as D-76 are excellent. With this particular formula, the time of development is from 12 to 14 minutes at 65° F.

The temperature of the developer and other processing solutions should not be over 65° F. (18° C.) or the gelatin may swell to such an extent that the image dots will be thrown out of register.

The negative is fixed, washed and dried in the usual way. It is important, however, that drying be uniform and not forced by the use of heat. If the emulsion is allowed to swell and become soft during washing or drying the image may not register with the viewing screen.

The negative should be fully exposed with brilliant shadow detail and of rather lower contrast than would be required for ordinary black and white work.

The Positive.—The positive is made by contact printing on a transparency or process plate. The exposure is made in the usual way except that an undiffused source of light, such as a single 25 watt electric lamp, should be used at a distance of 5 to 6 feet to secure sharp images of the dots constituting the image. The positive is developed, fixed, washed and dried in the usual way, care being taken to avoid any circumstance which would cause swelling of the gelatin to such an extent as to affect the registration of the image with the viewing screen.

The positive transparency should be bright, clear and of medium density. An examination with a low power magnifying glass should reveal clearly defined dots in both the highlights and the deepest shadows. Dense, clouded positives should be made over.

Registration.—The final operation consists in registering the positive transparency with the viewing screen. This requires a little practice. Place the viewing screen and the transparency face to face, with the screen first in the line of sight. Hold the two by one corner with the first finger and thumb of one hand. The opposite edges of the two plates are grasped by the thumb and forefinger of the other hand so as to permit the movement of the one with respect to the other by easy and minute stages. This method of holding the two plates enables the plates to be moved over each other by easy and minute stages. If at first a cross-plaid pattern appears, the plates should be moved over each other in such direction that the plaid becomes larger and larger, until it eventually disappears. At this stage, the minute squares of the viewing screen and positive are in alignment, and if the correct colors are not in evidence the slightest movement of the screen in a straight line towards the required color will bring out the correct color in a flash. The correct color will be seen if the plates are viewed a little to one side. Having arrived at the right position, the two plates are held together by means of two or more strong letter clips, the two opposite edges bound with lantern slide binding strip, and the other two edges similarly bound. Care should be taken to move one clip at a time. Allow ten minutes for the binding to set and the color transparency is completed.

Sources of Failure with Separate Screen Plates.—

Defect	Cause	Remedy
Transparency shows an excess of blue and very little red or yellow.	Negative badly underexposed.	None.
Transparency has a strong violet color all over.	Negative was made without a filter.	None.
Colors are muddy.	The positive is overexposed and underdeveloped or the plate used does not produce sufficient contrast for the process.	Make a new positive with increased contrast.
Colors too bright.	The positive is overdeveloped or the plate used results in too much contrast for the process.	Make new positive with less contrast.
Colors very faint.	The negative has too much contrast.	Make a positive on a softer working plate.

Defect	Cause	Remedy
Center and ends of picture will not register at the same time.	Focal length of the lens used in making the negative was too short. Incomplete contact between screen and the plate.	None.
Positive will not register with viewing screen.	The image on either the negative or the positive has shifted because of (1) processing at high temperature (2) drying by heat or (3) excessive hardening in a hardening fixing bath.	If the positive is at fault, make a new one with greater attention to the conditions which result in excessive swelling of the gelatin.
Color is patchy; may be lacking altogether in some places.	Is usually due to uneven pressure in the plate holder when making the negative or in the printing frame when exposing the positive.	Examine the negative and positive carefully with a magnifier. If the dots are not sharp in some parts of the negative, it is at fault and there is no remedy. If the negative is sharp but there are areas in the positive in which the dots are unsharp, make a new positive with special precautions to obtain even pressure on the printing frame.

Making Three-Color Negatives from Screen Plate Transparencies.—Three-color negatives may be made from color transparencies made by the Kodachrome, Dufaycolor, Agfa, Lumicolor, or Finlay processes. In this way, color records may be made of moving objects without a special camera, three-color negatives made from the resulting color transparency and prints on paper from these negatives by any of the recognized methods of subtractive color printing.

The three-color negatives may be made either by contact or projection printing.

Any well designed apparatus for projection printing may be used in making enlarged three-color negatives from the color transparency, but it is well to construct a box to enclose the space between the lens and the easel in order to prevent stray light from reaching the film. The box should be painted on the inside with a matt black paint.

In making the negatives by contact, a printing cabinet provided with a constant light source is desirable. A 72 watt 4 volt bulb operated from a storage battery will be found satisfactory for this purpose. The light source may be diffused with a sheet of ground or opal glass. The light source should not be too intense, or the exposures will be too short to time accurately.

Whether the three-color negatives are made by projection or by contact printing, it is essential that a scale of neutral densities be placed along one side of the color transparency to enable the three negatives to be balanced for density and contrast. Such neutral density scales are available commercially in different sizes.

The transmission of the filter elements in screen plates overlap one another with the result that green is recorded not only under the green but to a certain extent under the red. Red, likewise, is recorded not only under the red, but partly under the green, and in like manner blue is recorded partly in blue and partly in green. In making three-color negatives from a screen plate transparency, it is necessary to compensate for the overlapping of the filters in the reseau by using filters which have narrower transmissions than those of the screen to avoid undue loss in brilliance and color saturation.

In making three-color negatives from Dufaycolor transparencies, three special filters, Nos. 15, 25 and 33 are supplied. In making three-color negatives from Kodachrome transparencies, the Wratten No. 29 (red), 61 (green), and 49 (blue) filters are recommended.

These filters are placed over the lens when making enlarged negatives, or at some point between the light source and the printing frame when printing on contact.

A fine grain, backed panchromatic film is suitable for making the three-color negatives. The exposure ratios and the developing times necessary to produce a set of negatives which balance as respects density and contrast vary with the light source, the film and the developer employed, and must be determined by trial. The scale of densities along one side of the negative is used for this purpose as when making the three-color negatives directly in the camera.

Three-Color Negatives from Finlay Negatives.—Three-color separation negatives for prints in any of the subtractive printing processes may be made from Finlay negatives by means of two block-out screens. These screens have a black and white dot formation so that when the screen is registered with the negative the areas representing two of the color sensations are blocked out so that only those required for that particular separation negative are recorded. One screen is used for both the red and the blue printer which is possible by shifting the block-out screen to a different position on the negative. The other block-out screen is used to make out the yellow printer.

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